
CFD Analysis of Liquid Argon Flow in 35 ton prototype and LBNF cryostats

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Stephen Gent
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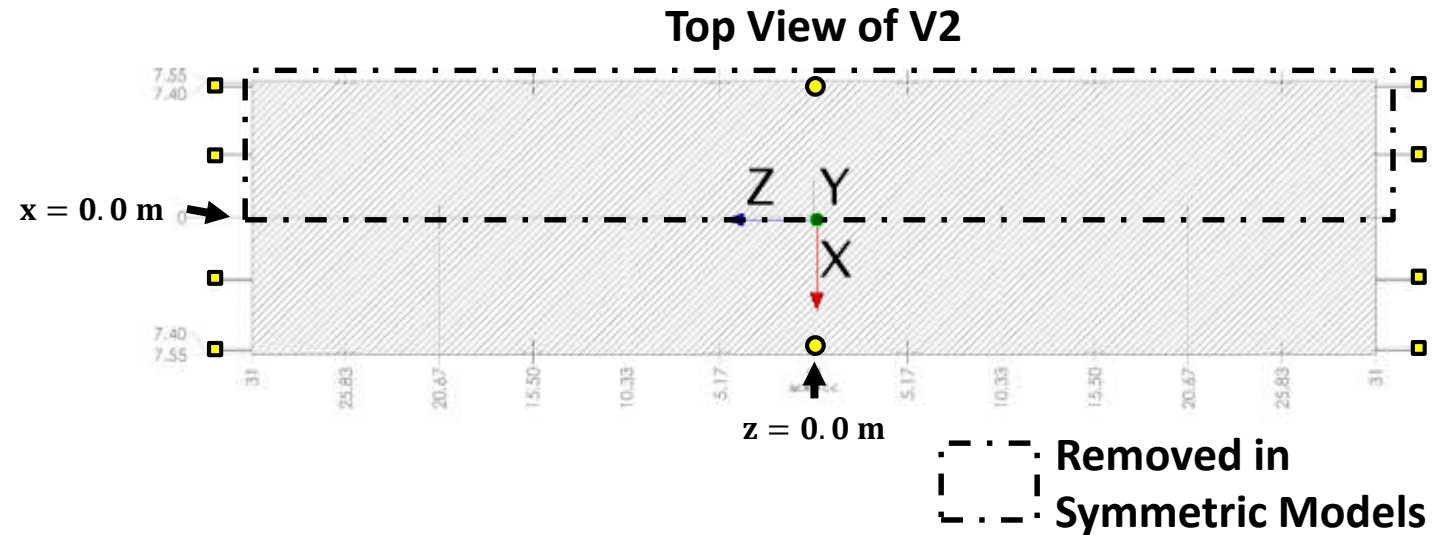
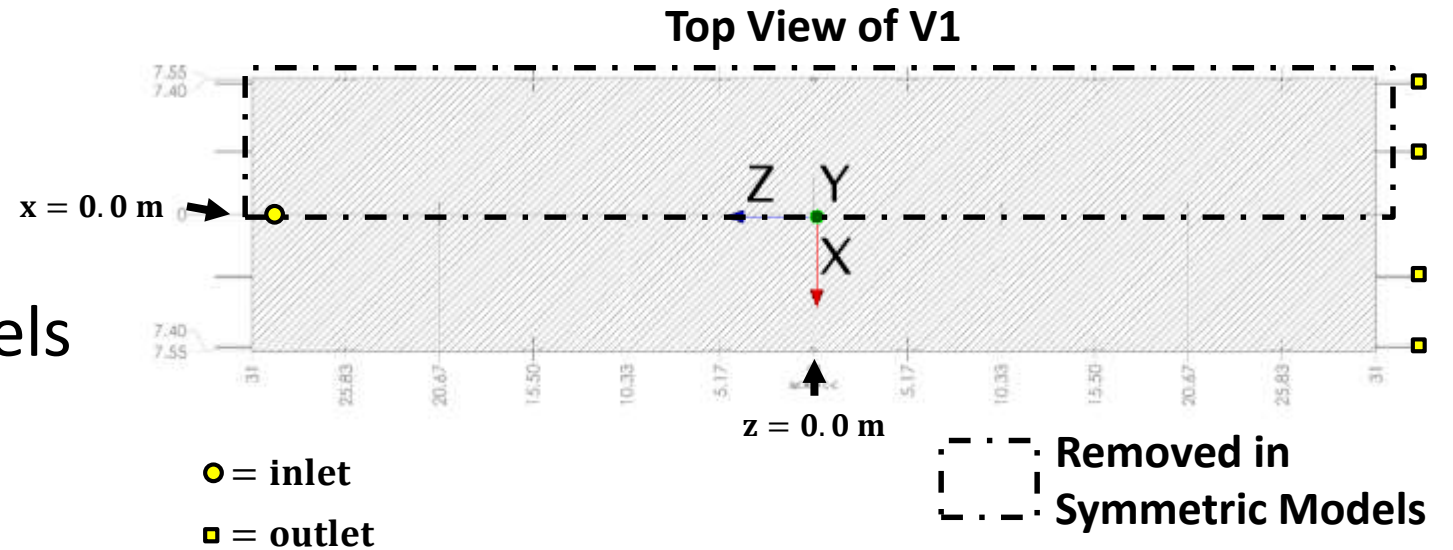
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June 27, 2017

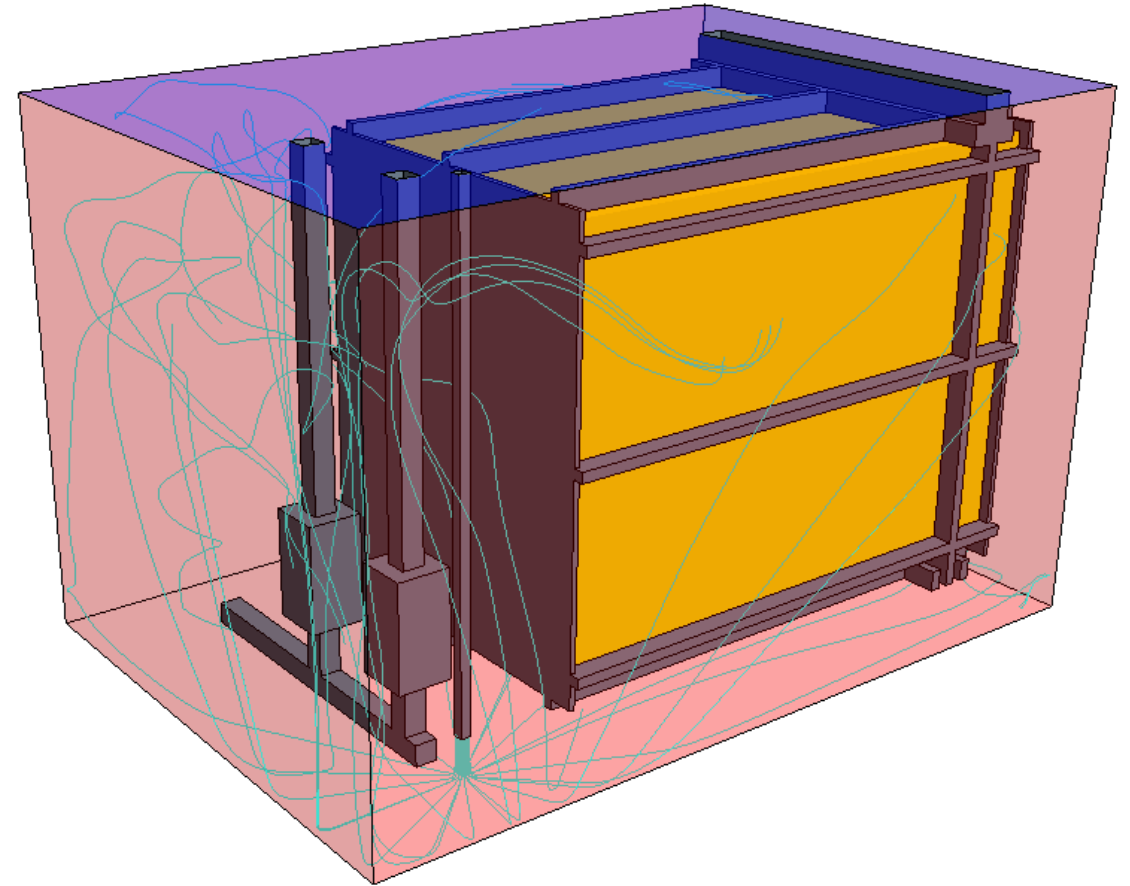
Simulations to Date

- 35 Ton
- V1 Configuration:
 - Full and symmetric models
- V2 Configuration:
 - Symmetric only



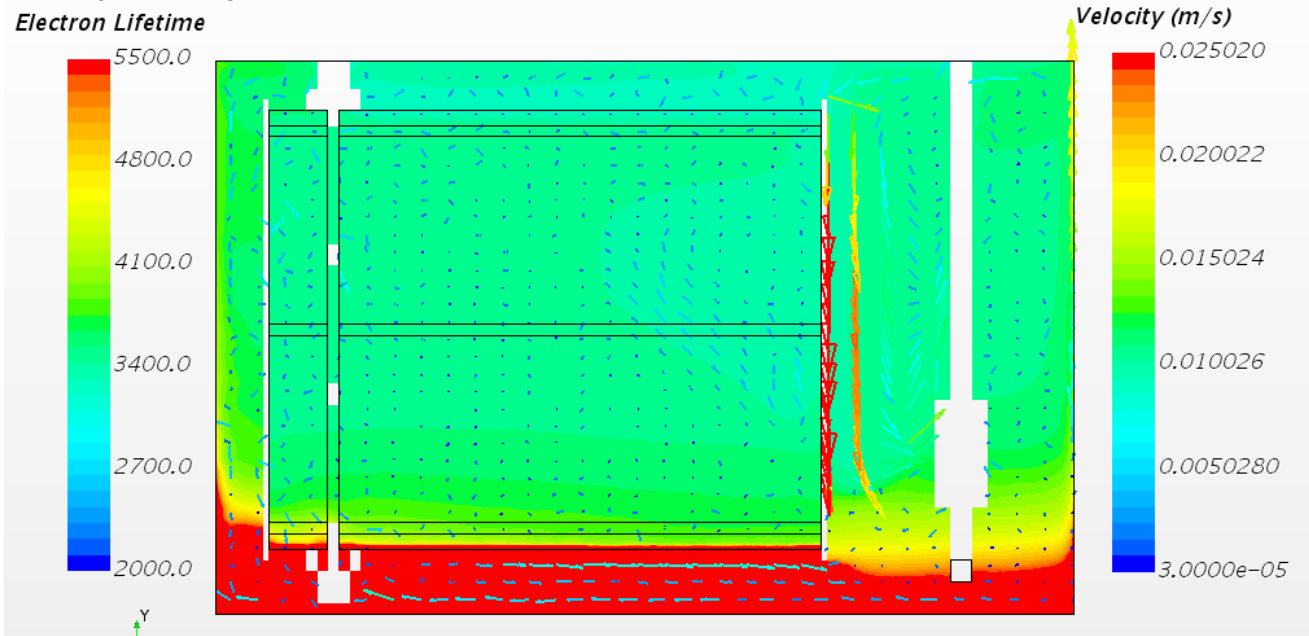
35 Ton Simulation

- Red: heat enters through wall
- Blue: constant temperature, impurity flux
- Yellow: 23% porous wall
- 9.5 GPM LAr flow rate
- Inlet temperature: 87.808

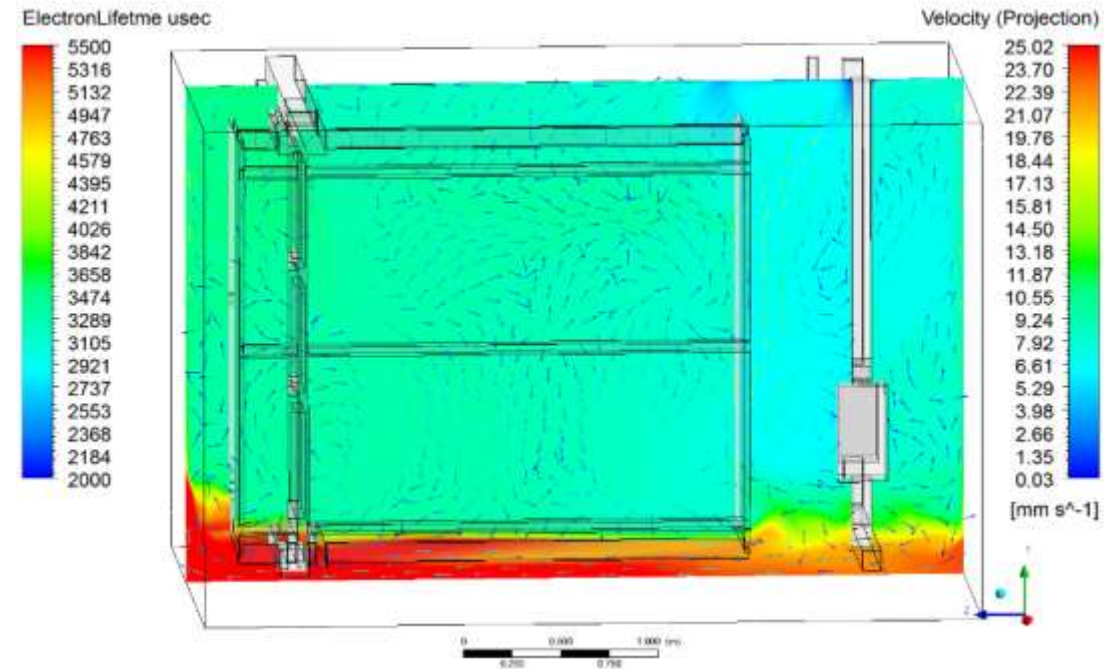


35 Ton Simulation

Impurity Distribution

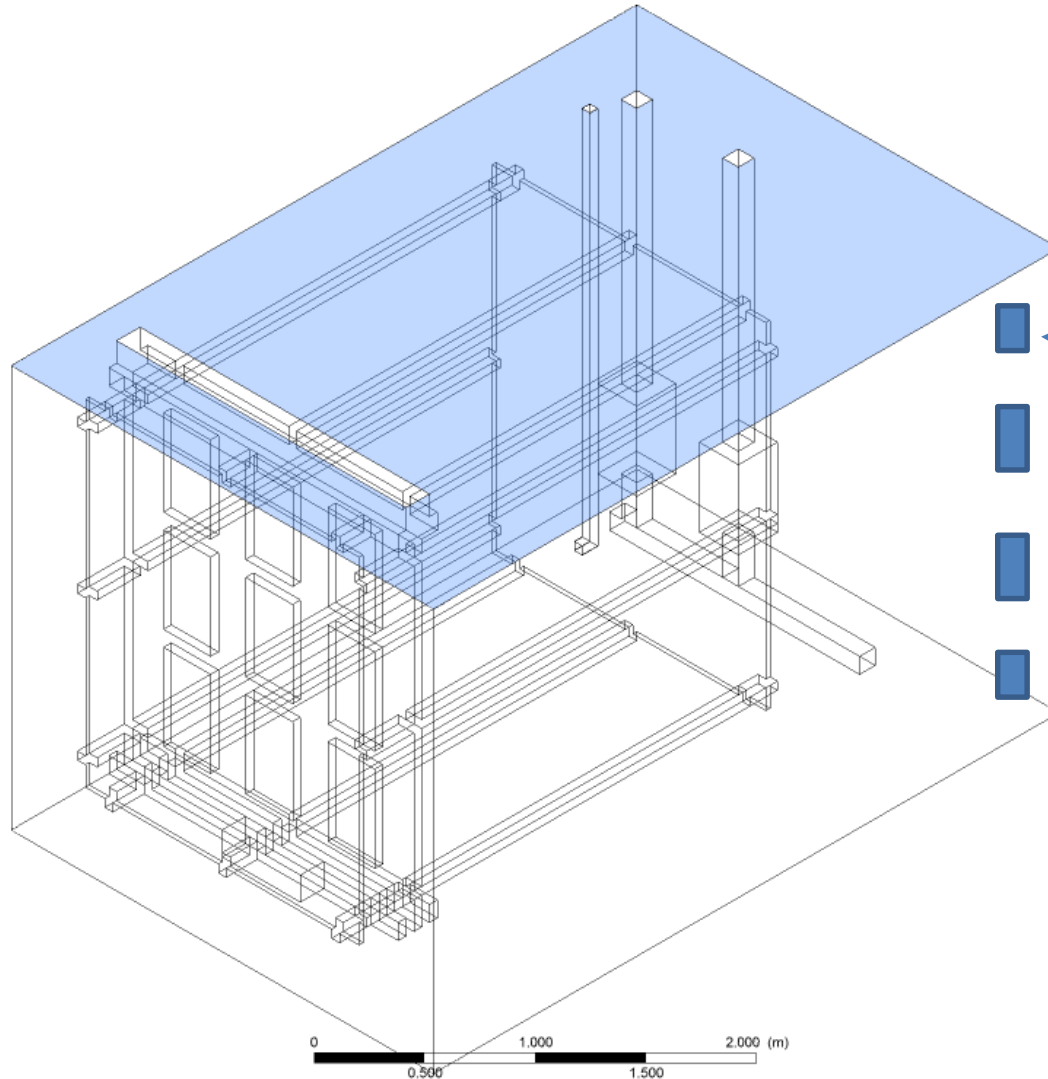


Fermilab Results



(Erik Voirin, Fermilab)

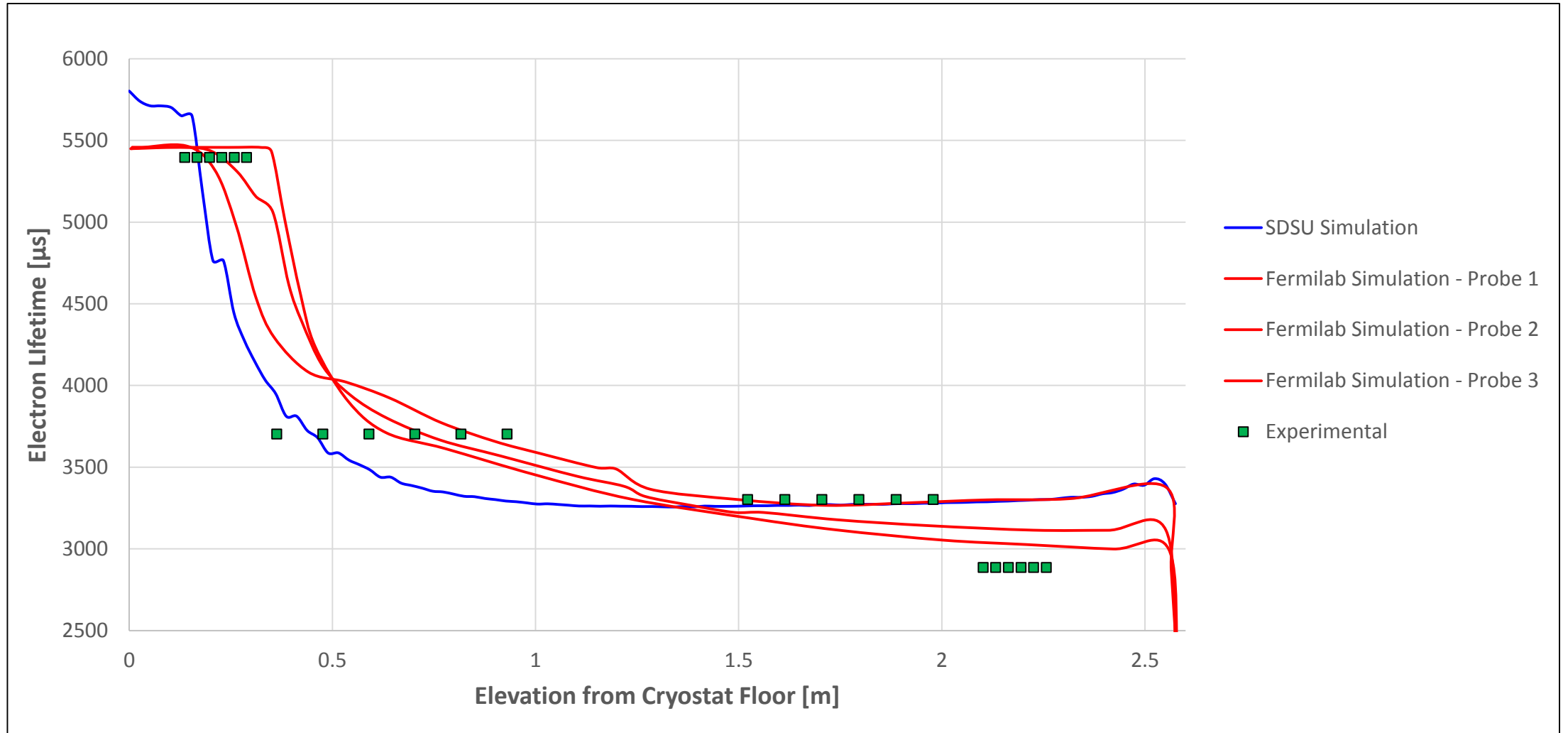
35 Ton Simulation



4 purity monitors in
this corner
(Geometry Not accounted
for in CFD model)

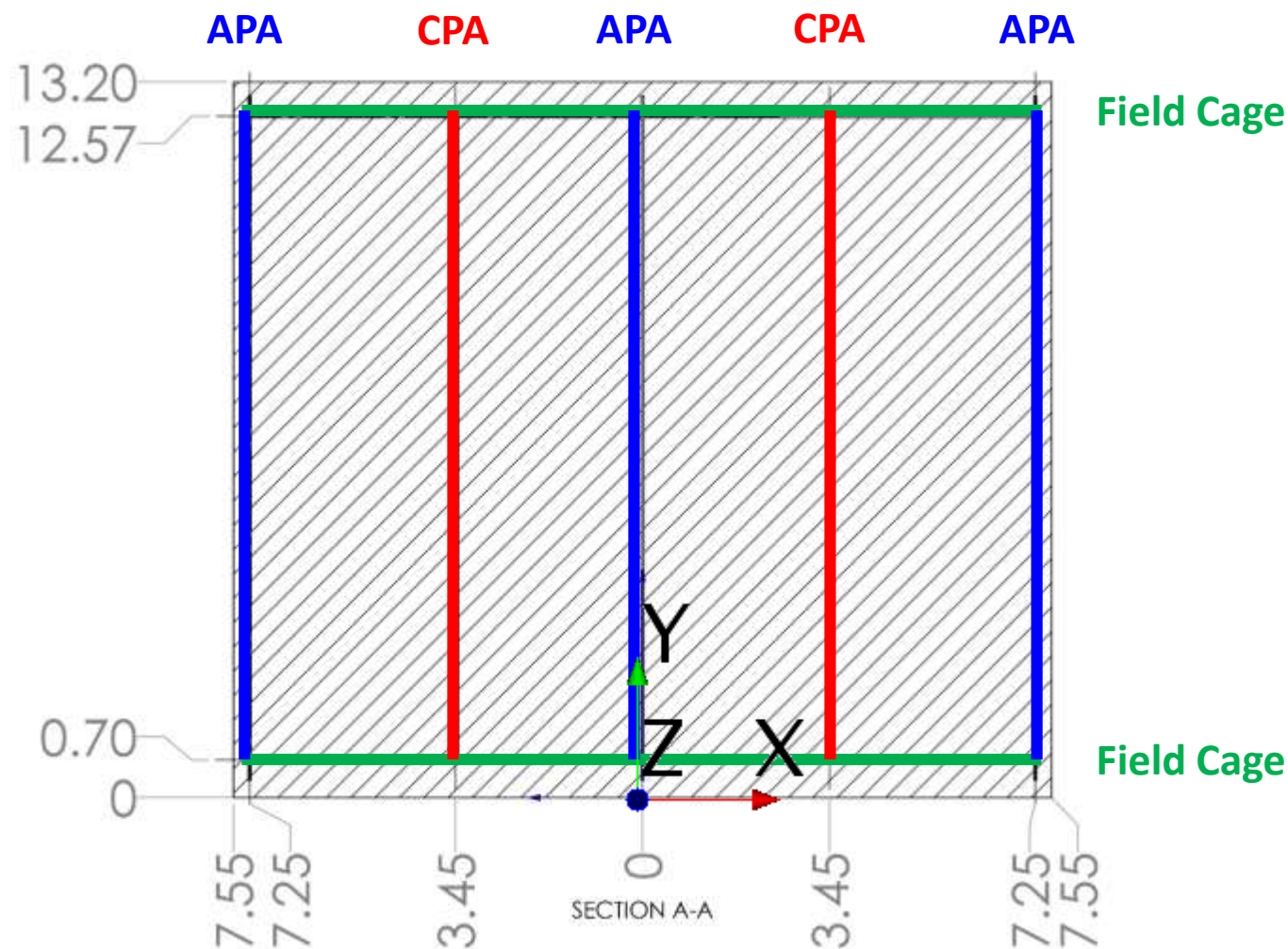
(Erik Voirin, Fermilab)

35 Ton Simulation

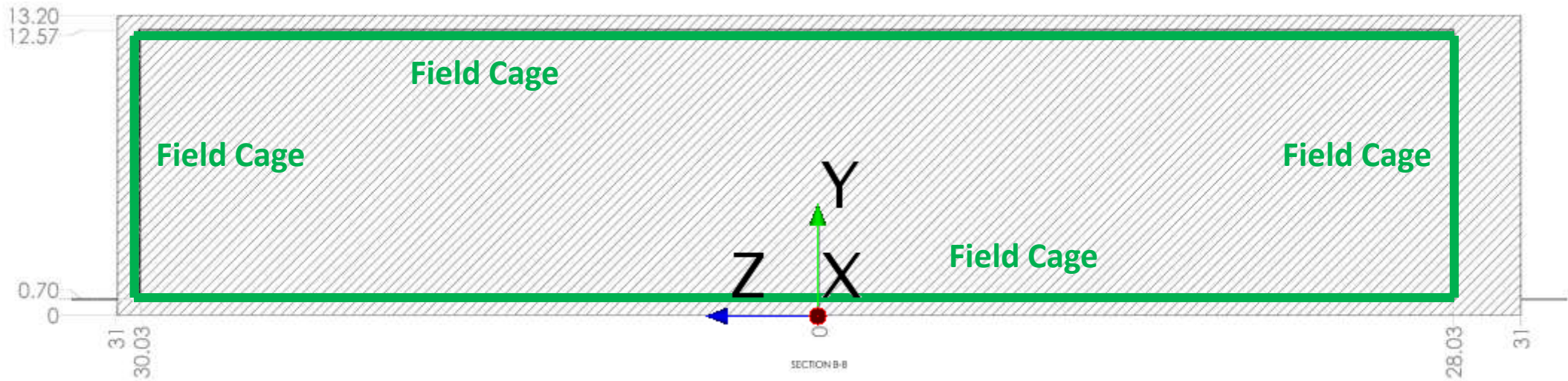


LBNF Cryostat - Geometry

- APA – approx. 80% open
- CPA – impermeable
- Field Cage – 23% open



LBNF Cryostat - Geometry

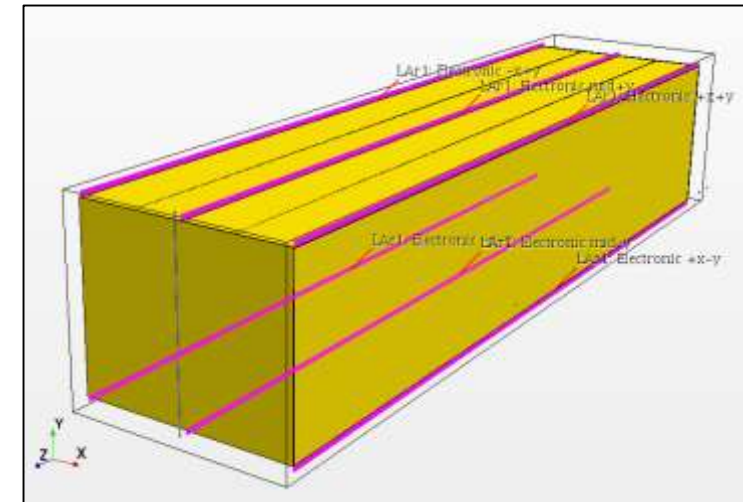


LBNF Cryostat – Boundary Conditions

- Top Wall (LAr surface):
 - LAr Saturation Temperature: 88.348 K
 - Passive Scalar Flux: 1
- Remaining Exterior Walls:
 - Heat Flux: 7.2 W/m²
- Electronics Surfaces:
 - Total Heat Source: 23,700 W
- Inlet Temperature:
 - Maintained at 0.4418 K above outlet temperature to account for pump work
 - Flow rate in table on the right
- Porous Regions: Settings in previous slides

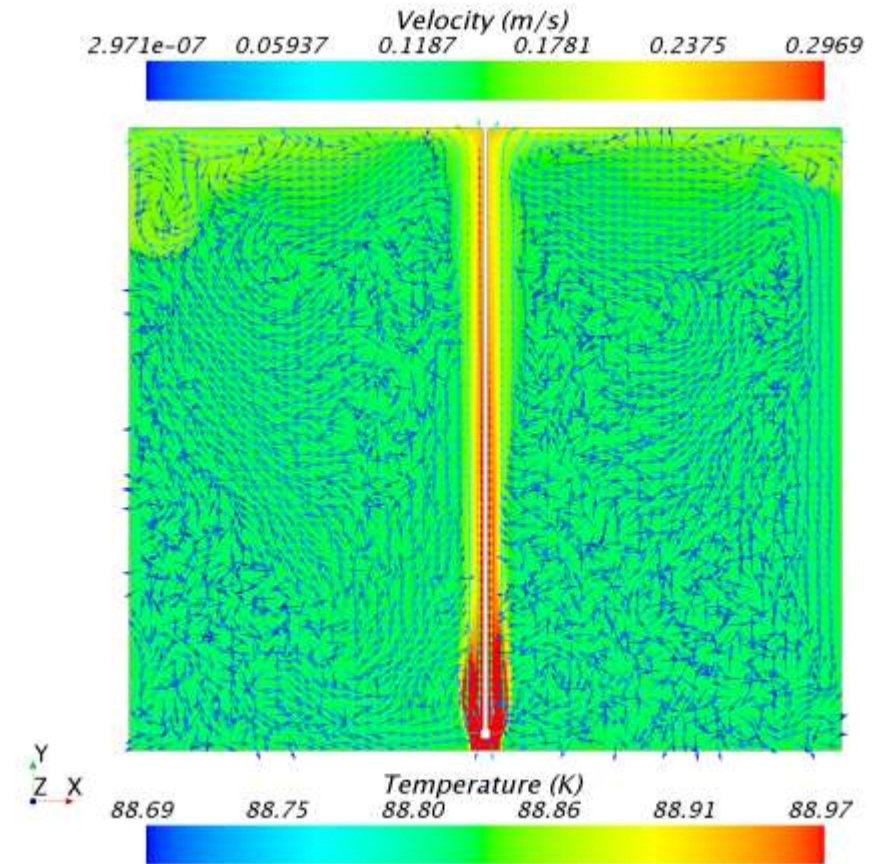
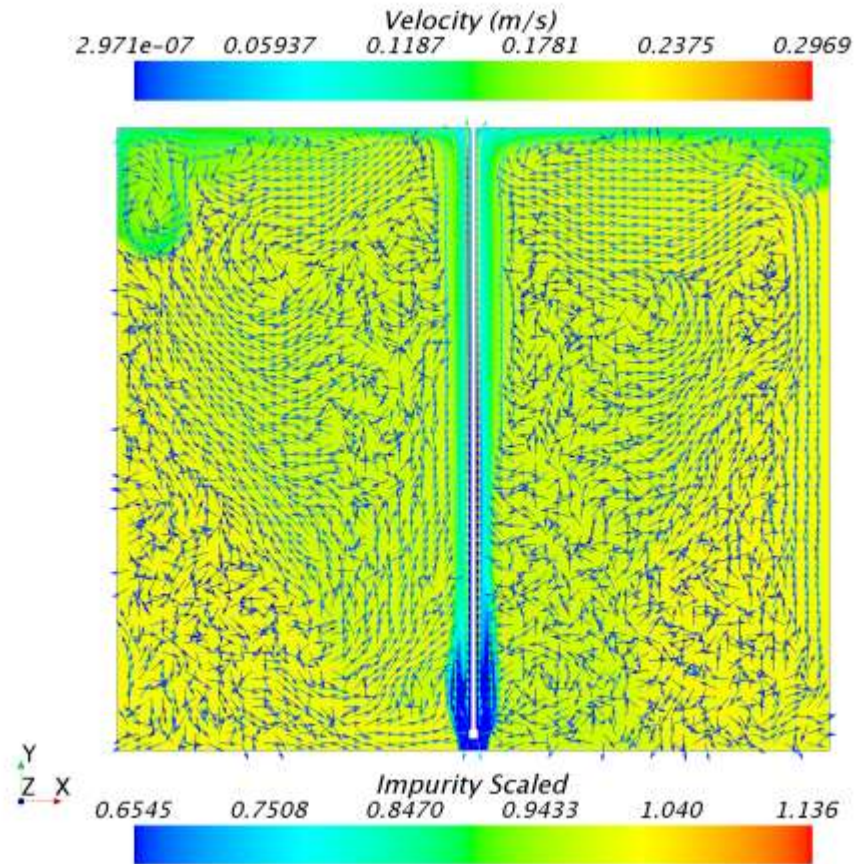
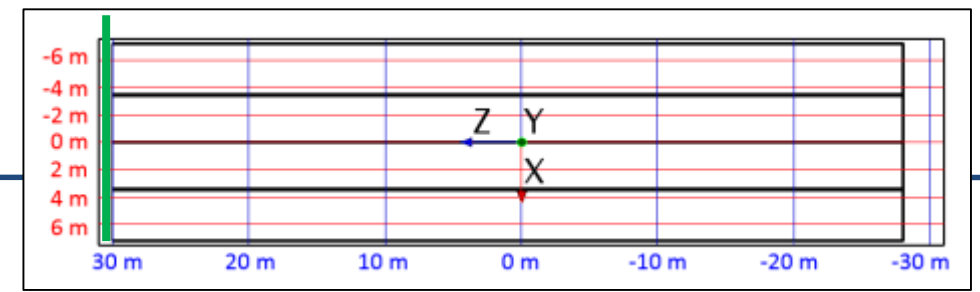
	V1 Full	V1 Sym.	Latest Sym.
Inlet Flow Rate	4 Pumps	4 (2) Pumps	1 (0.5) pump
# of Inlets	1	1 (0.5)	12 (6)
# of Outlets	4	4 (2)	7 (7)

Single Pump = 103 GPM



Electronics Surfaces in pink

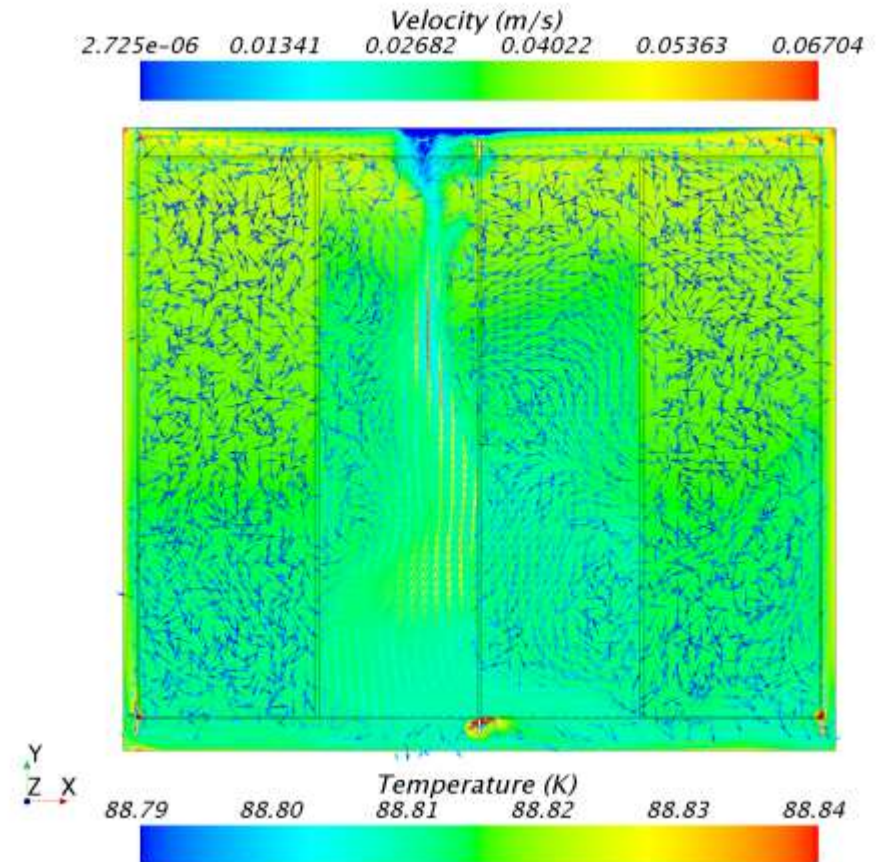
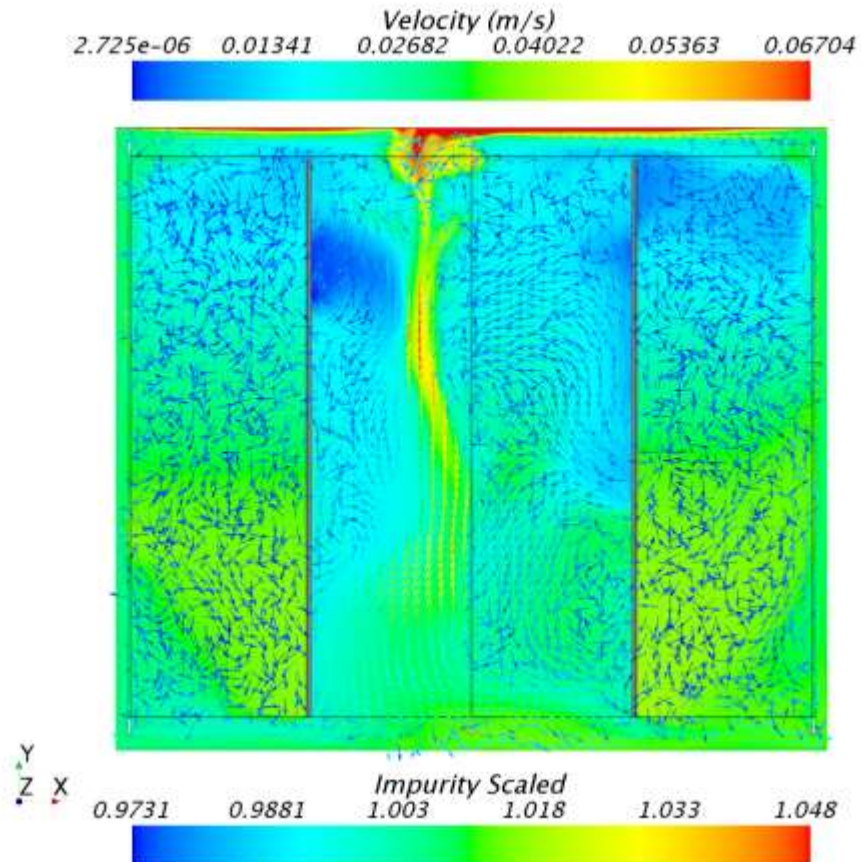
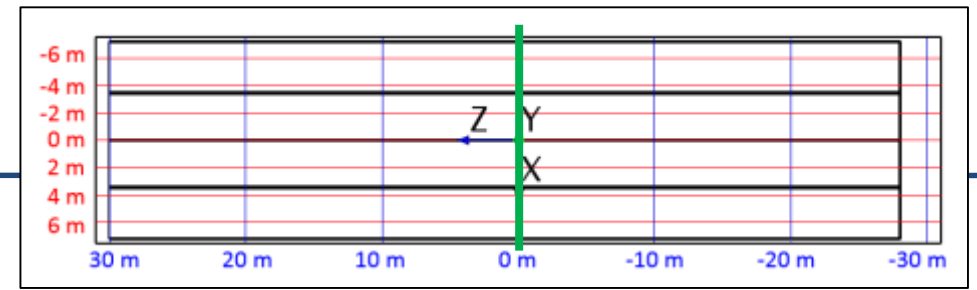
LBNF V1: Symmetry at $z = 30.5$ m plane (pump discharge)



LBNF V1: Symmetry

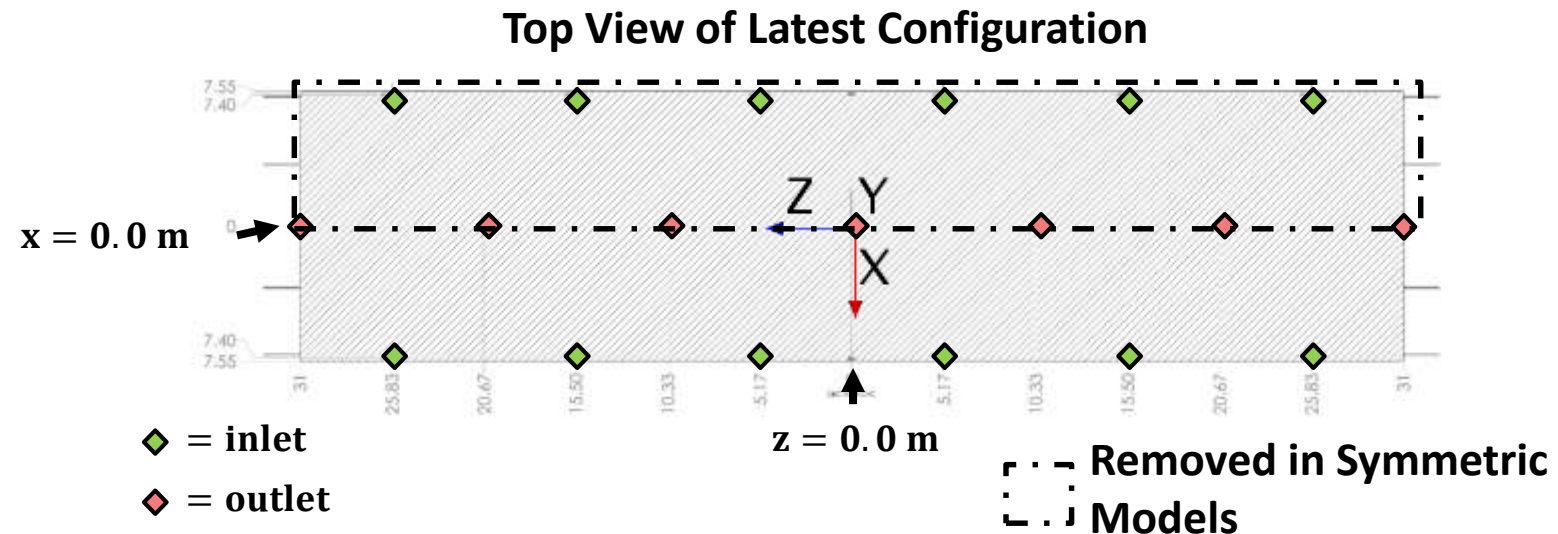
$z = 0$ m plane (center of cryostat)

$z = 0$ m plane (center of cryostat)



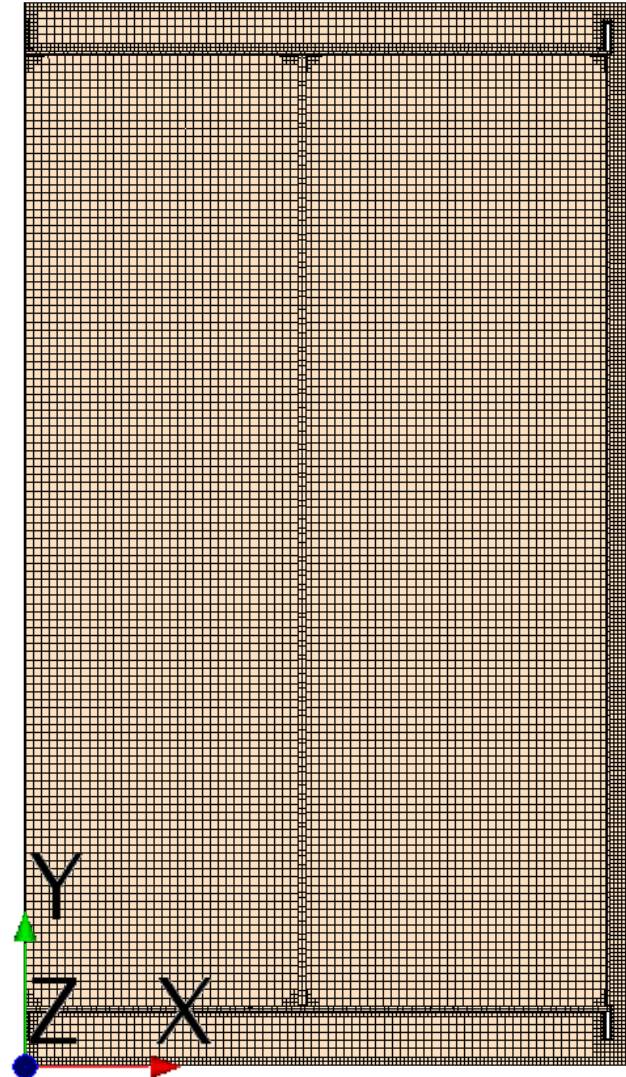
Simulations to Date (Continued)

- Latest Configuration:
 - Symmetric: standard operating conditions, electronics turned off, and half LAr flow rate.
 - Running full model: Erik Voirin's results showed significant asymmetry.



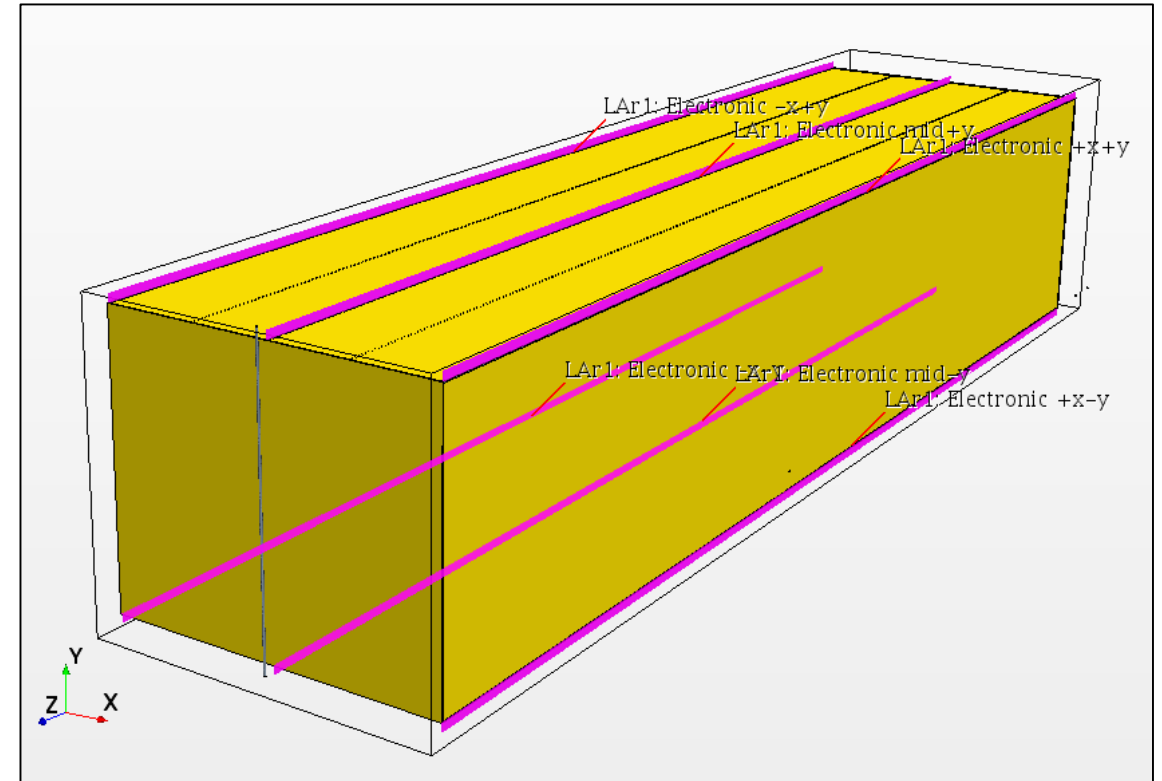
Mesh Validation

- Used two mesh types with varying levels of refinement.
- Solutions have been in agreement.
- Polyhedral meshes require more time (about 30%) to solve the passive scalar for impurity distribution.
- Currently using trimmed cell mesh (consists of cubes of varying sizes).

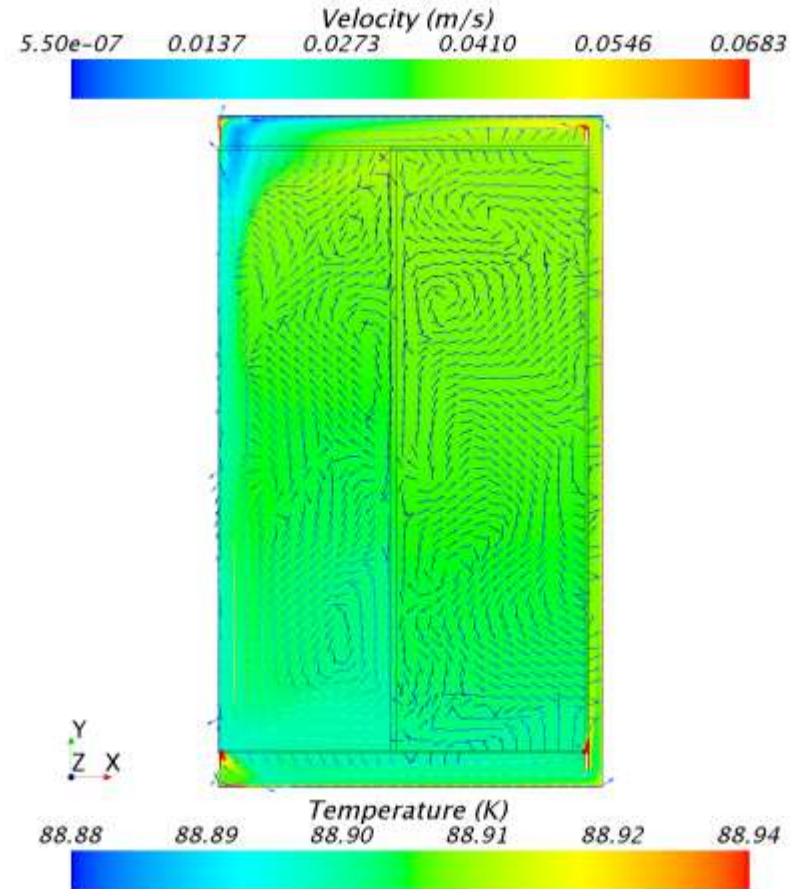
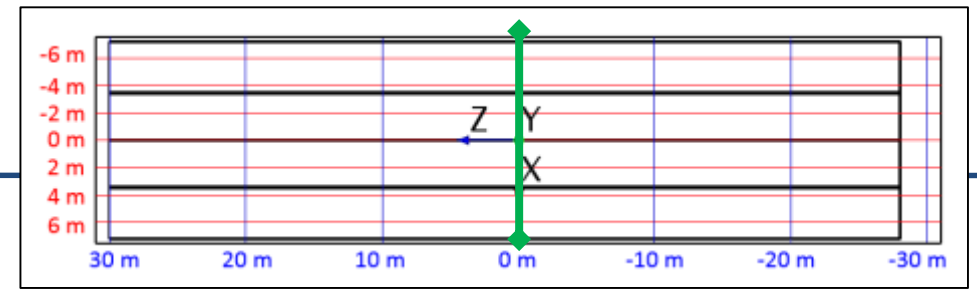


Electronics Turned Off

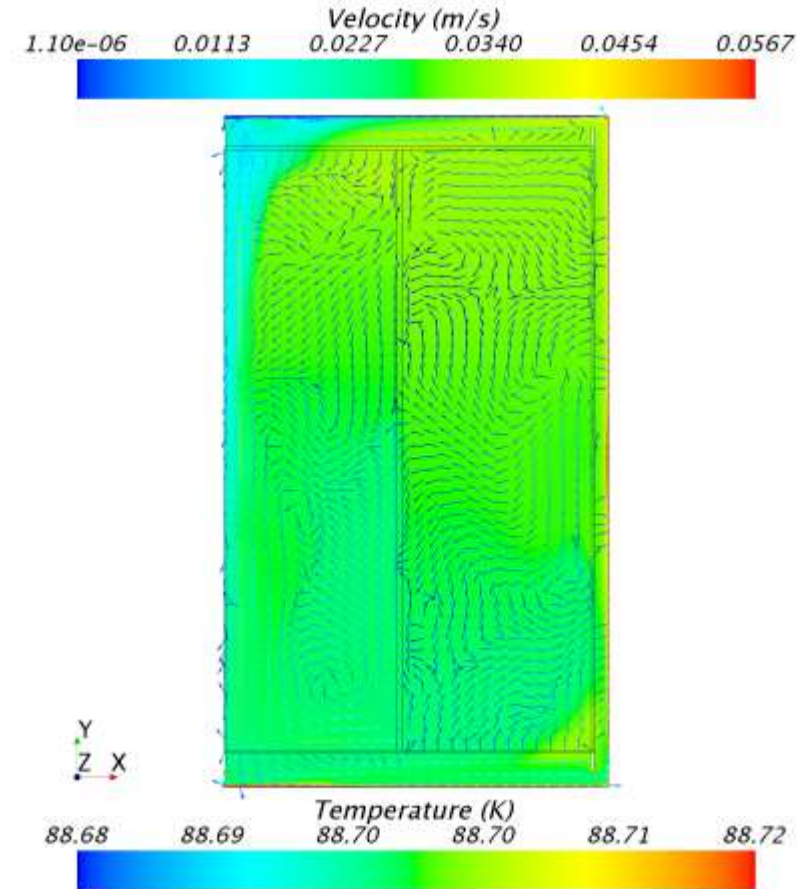
- Heat flux on electronics set to 0.0 Watts.
- No other changes.



Electronics Off: Temperature at Z = 0.0 m In Line with Outlet

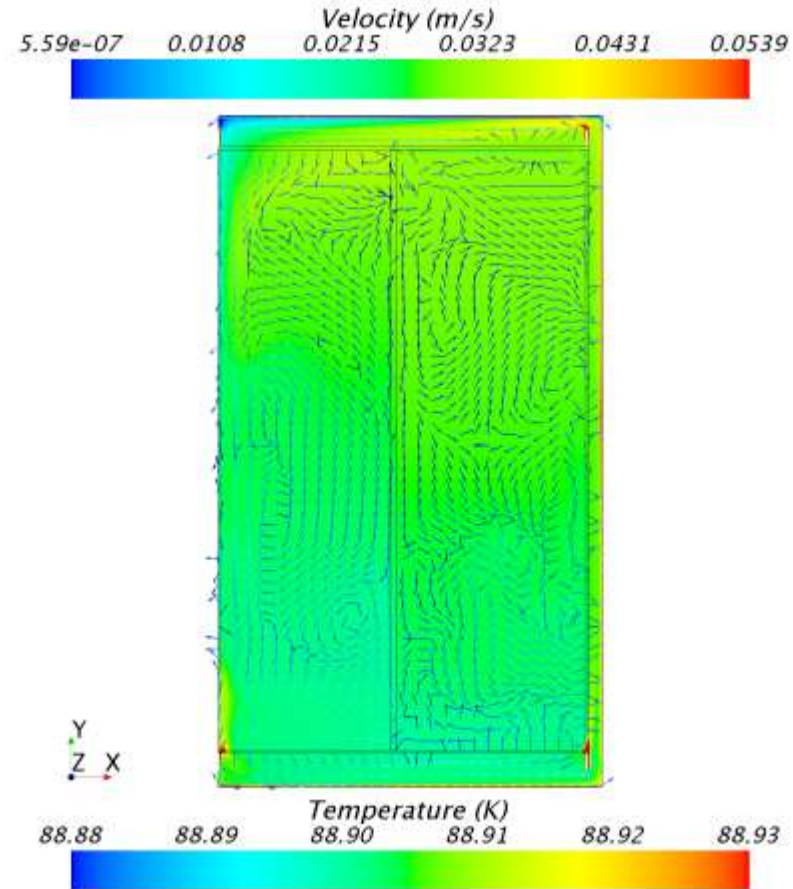
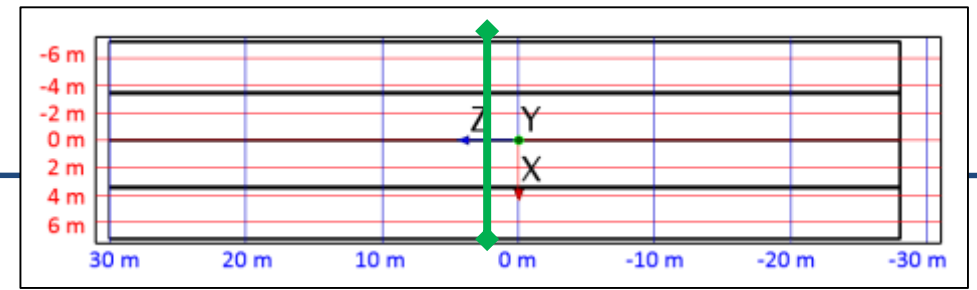


Electronics On

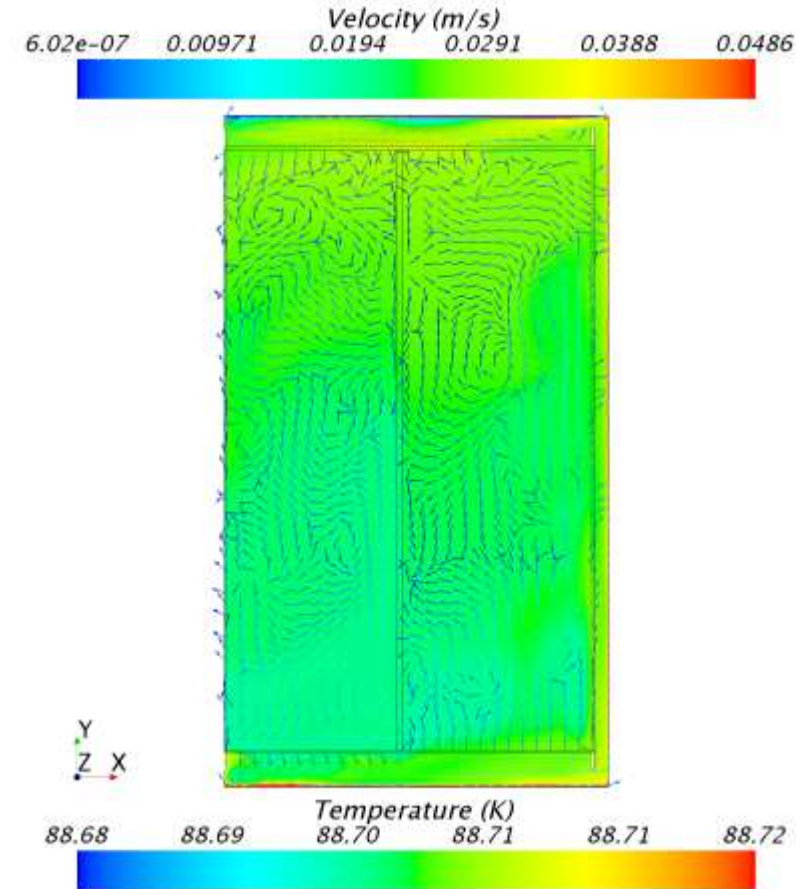


Electronics Off

Electronics Off: Temperature at Z = 2.59 m Between Inlet and Outlet

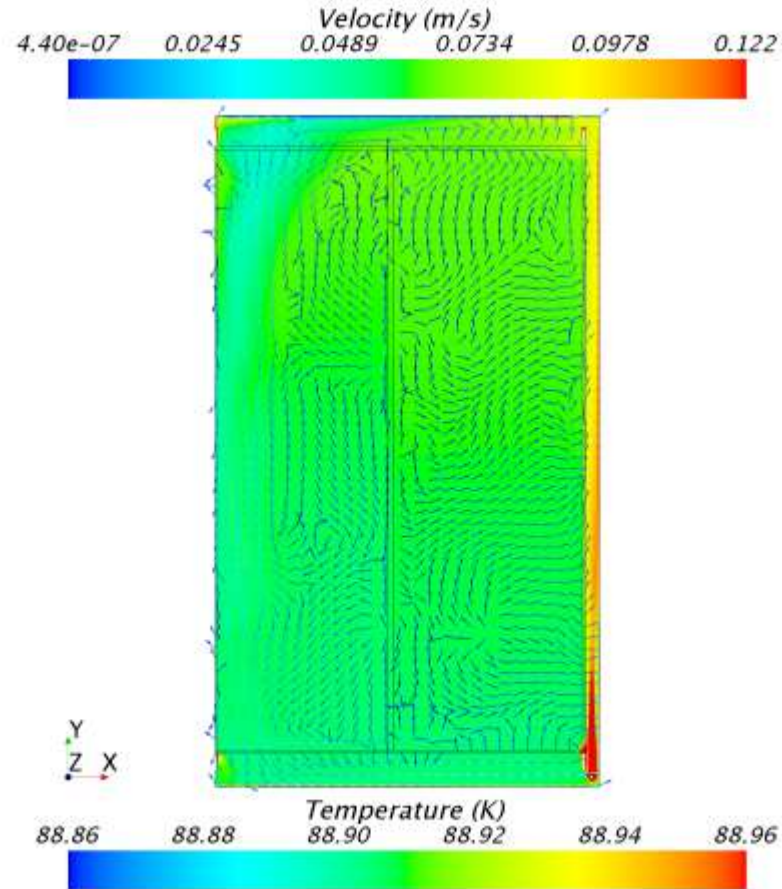
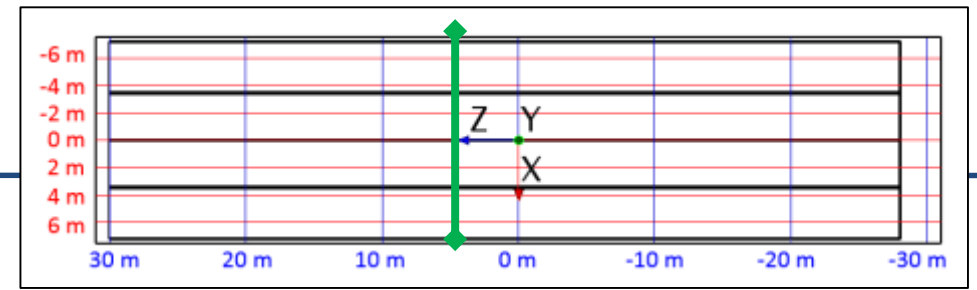


Electronics On

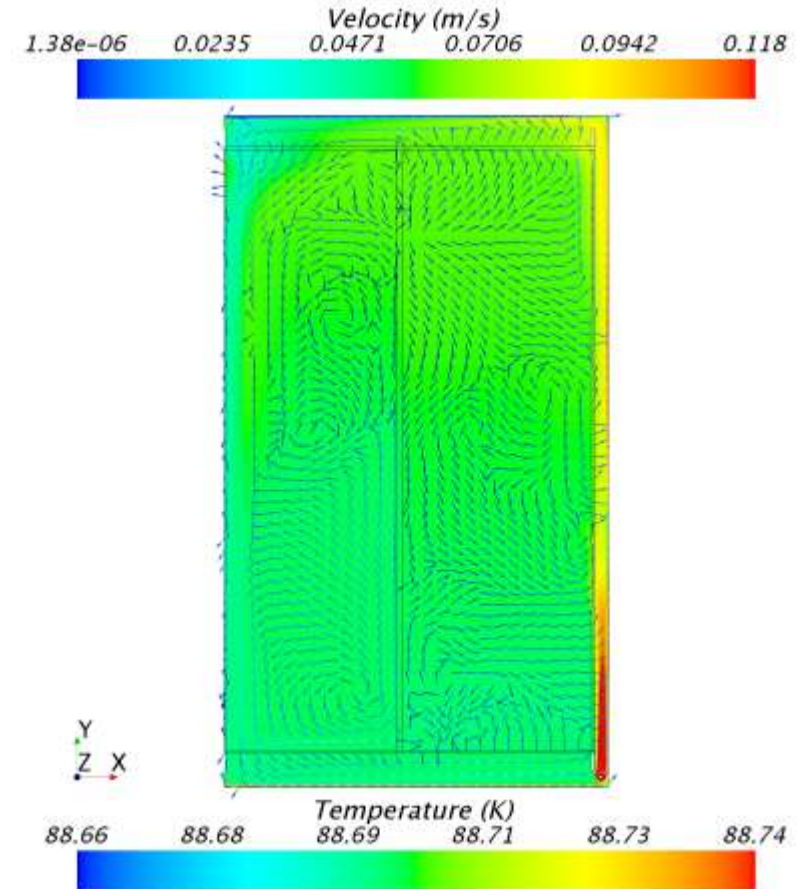


Electronics Off

Electronics Off: Temperature at Z = 5.17 m In Line with Inlet

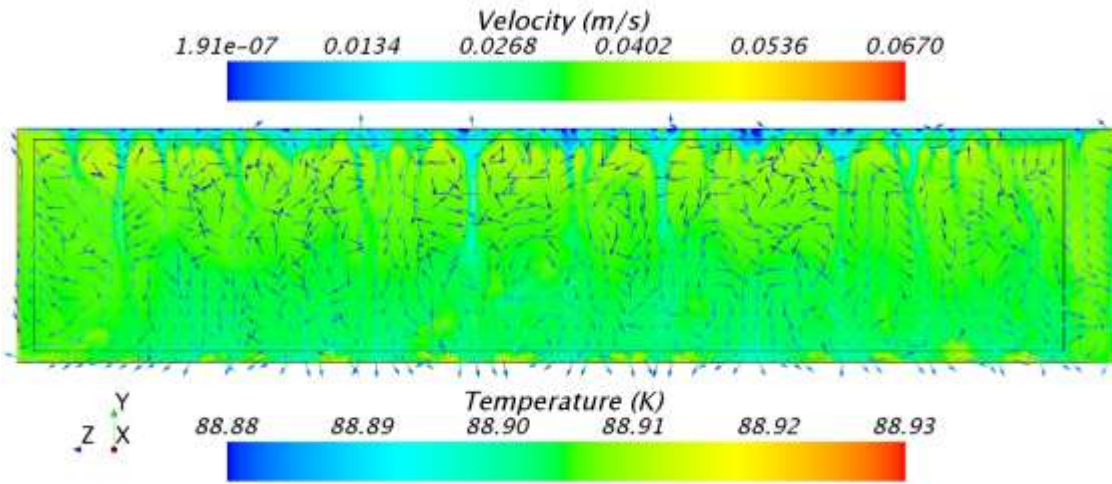
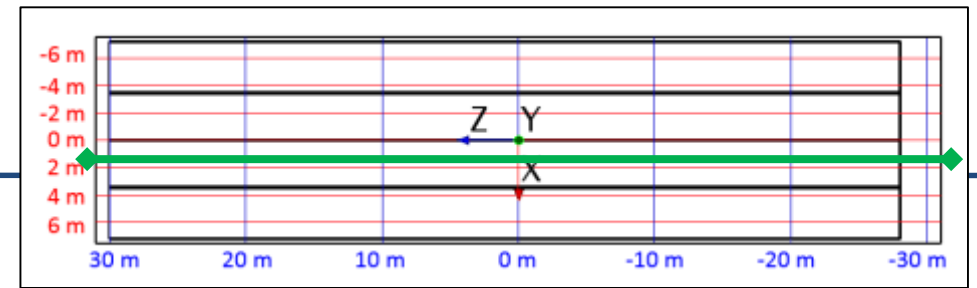


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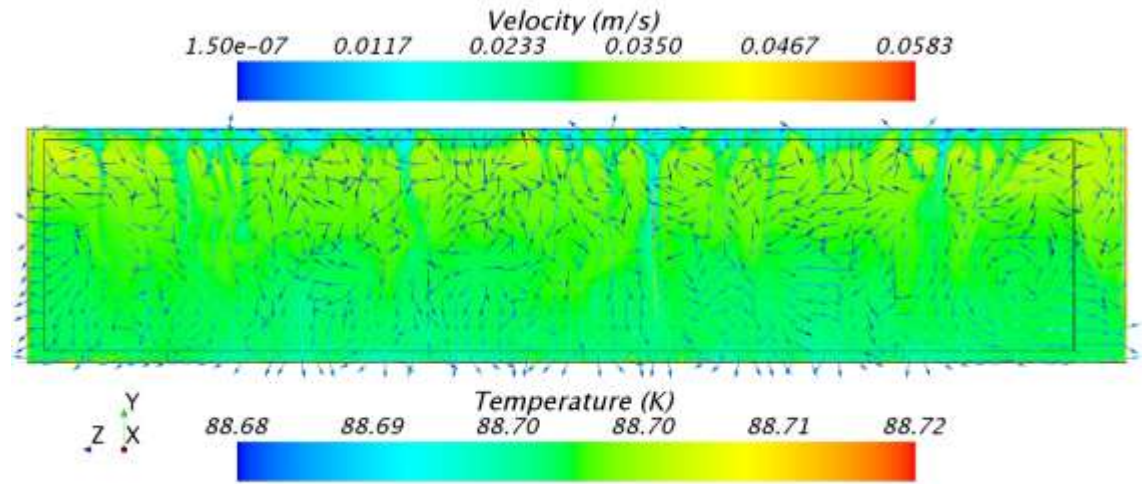


Electronics Off

Electronics Off: Temperature at X = 1 m

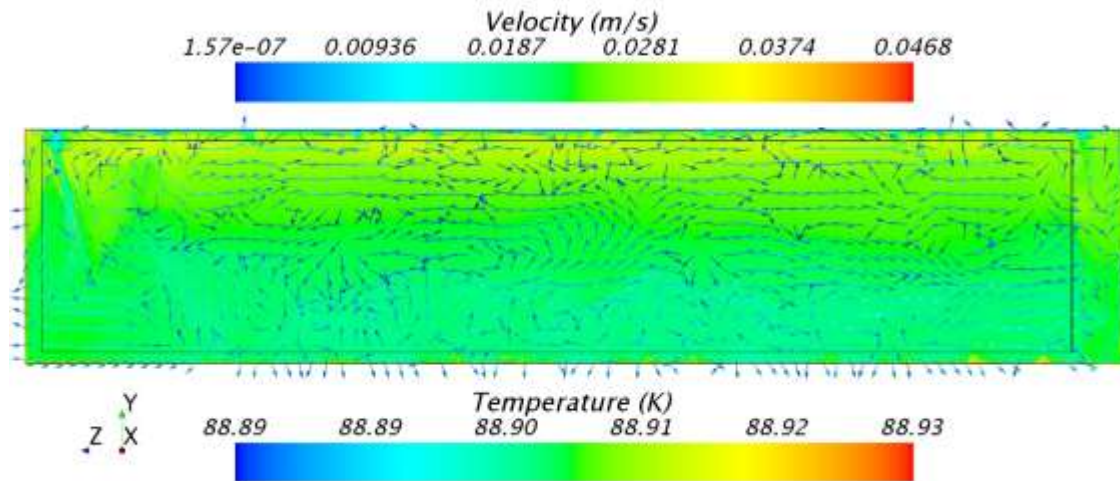
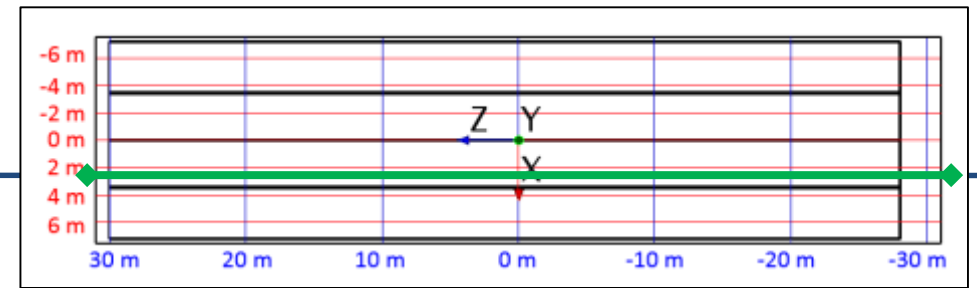


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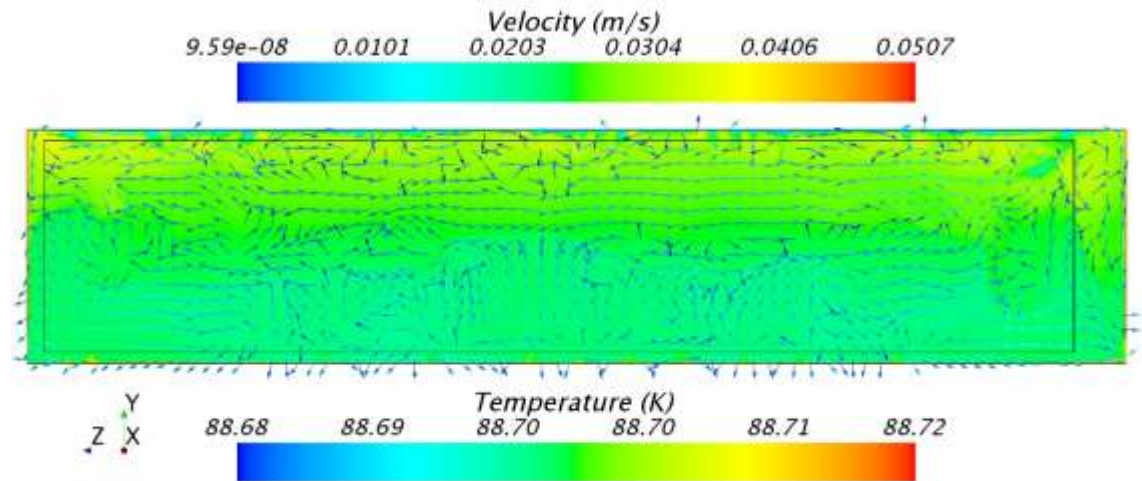


Electronics Off

Electronics Off: Temperature at X = 3 m

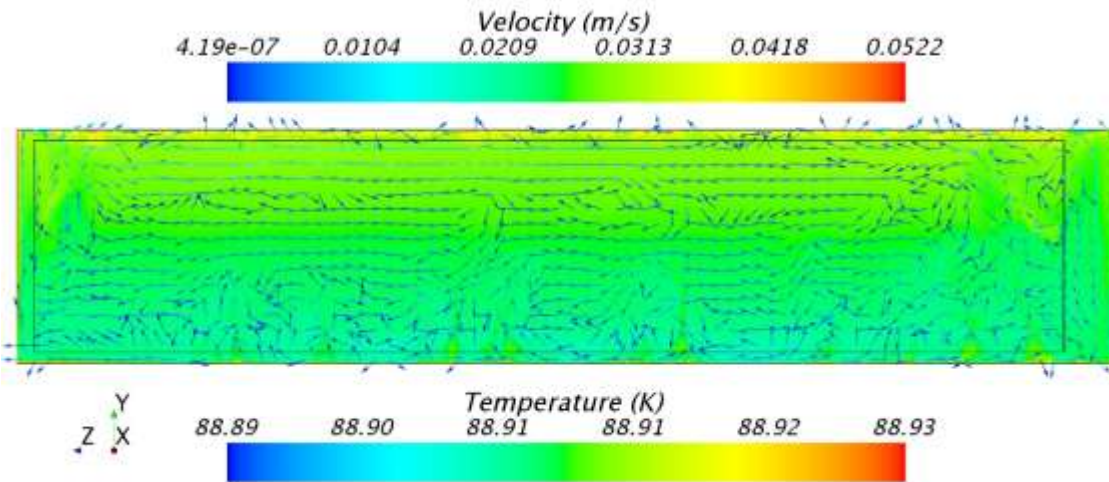
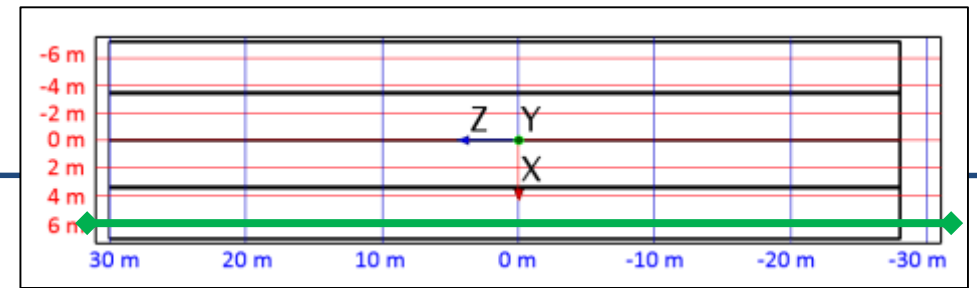


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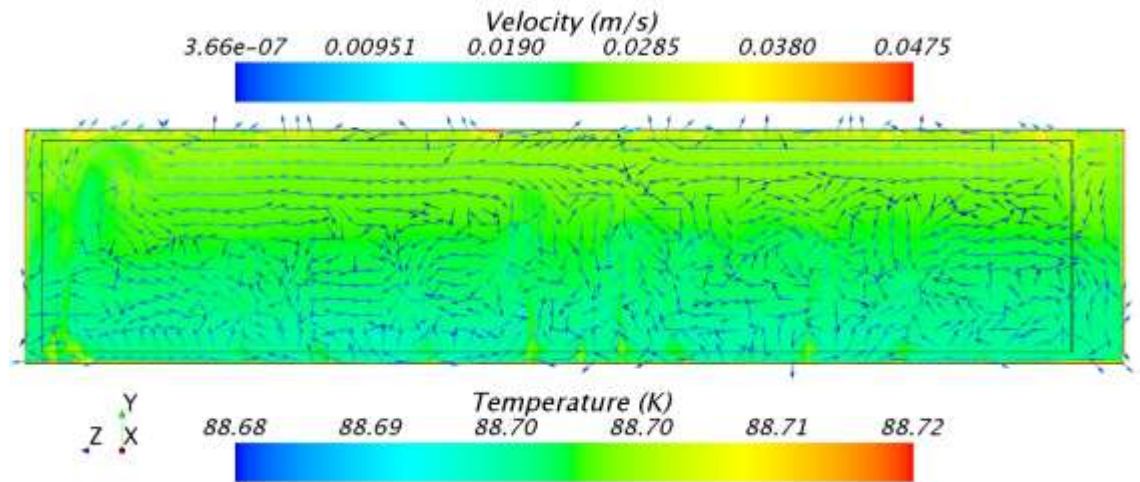


Electronics Off

Electronics Off: Temperature at X = 6 m

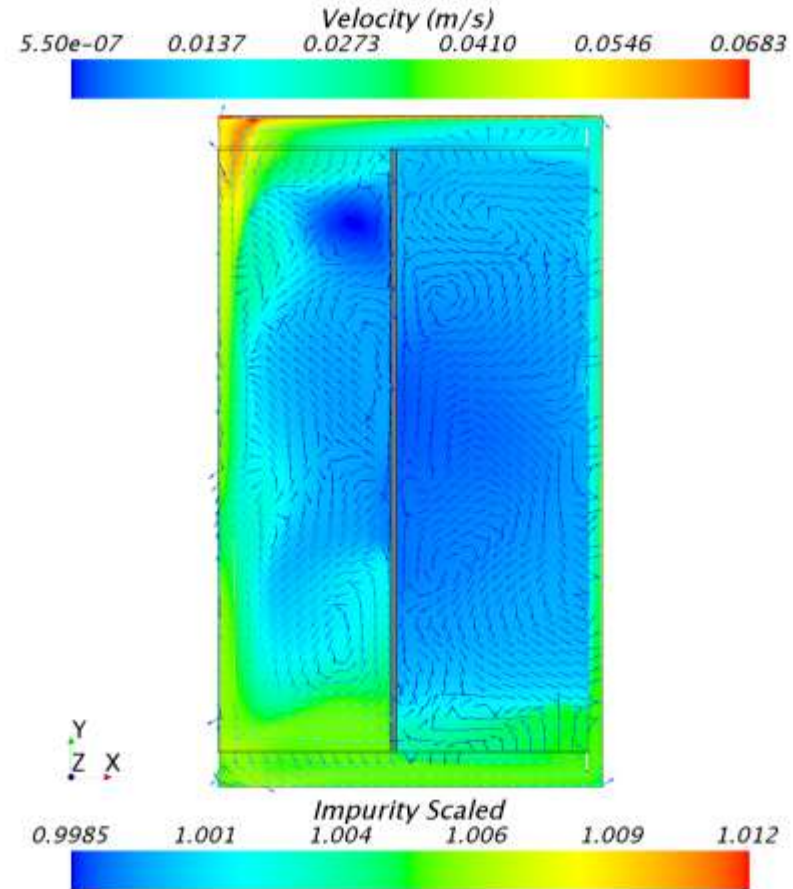
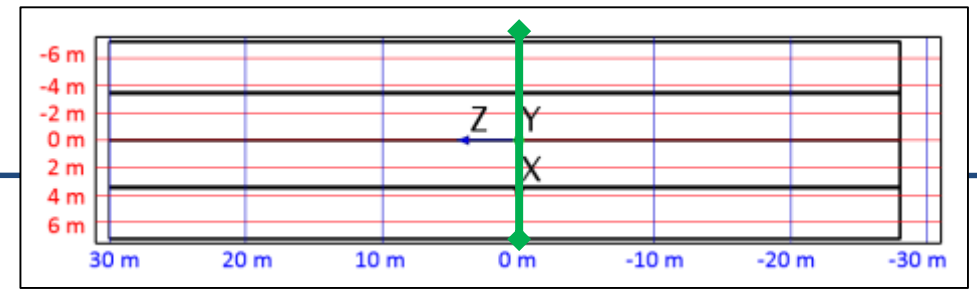


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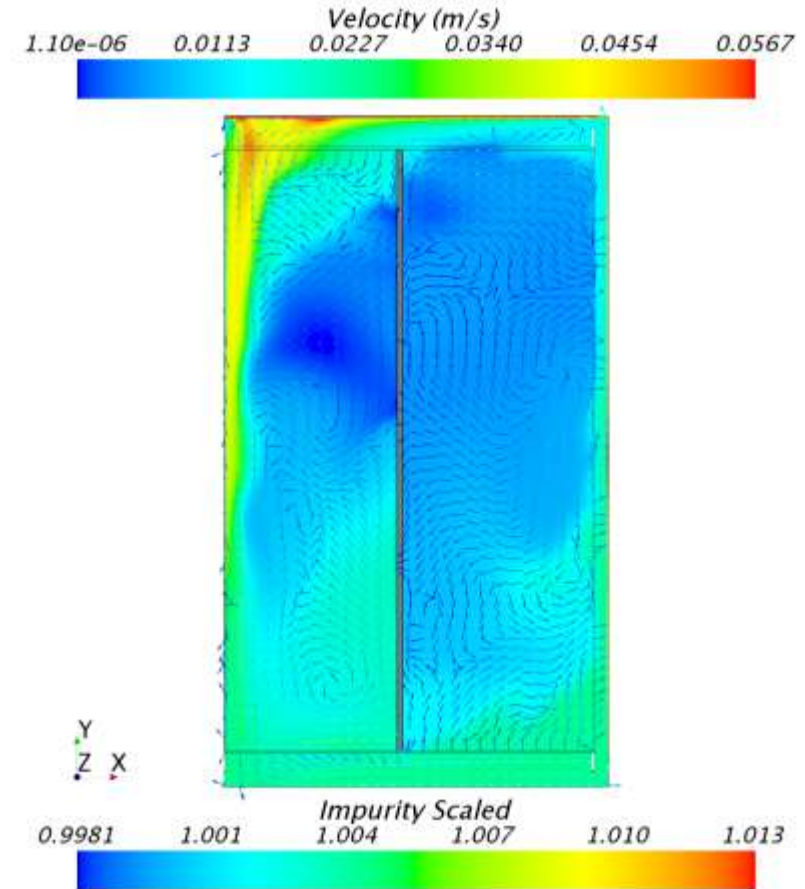


Electronics Off

Electronics Off: Impurity at Z = 0.0 m In Line with Outlet

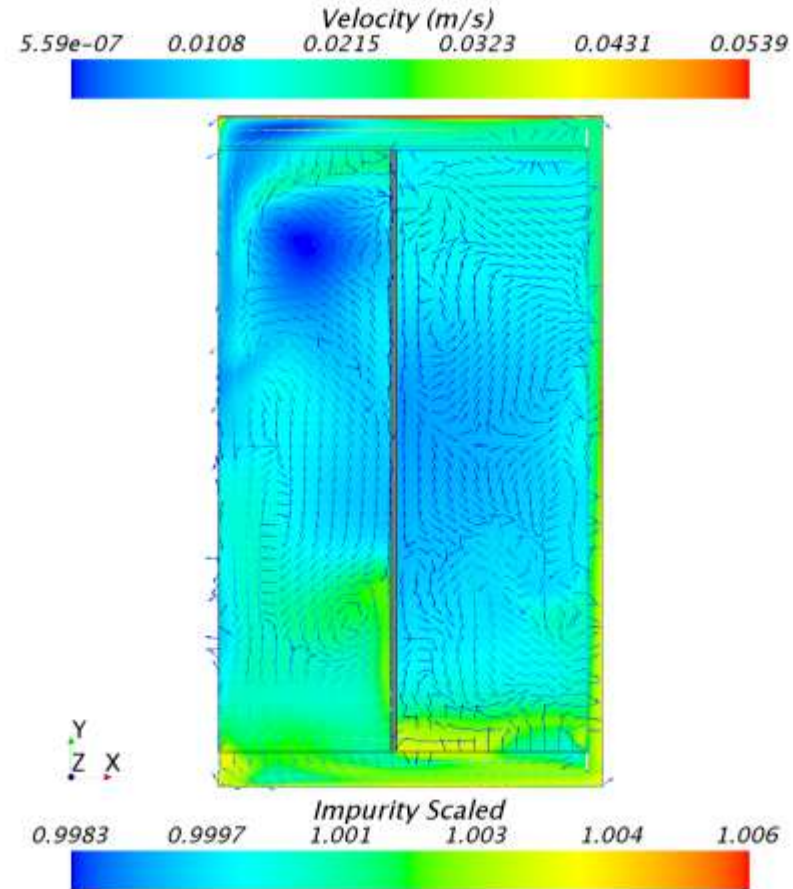
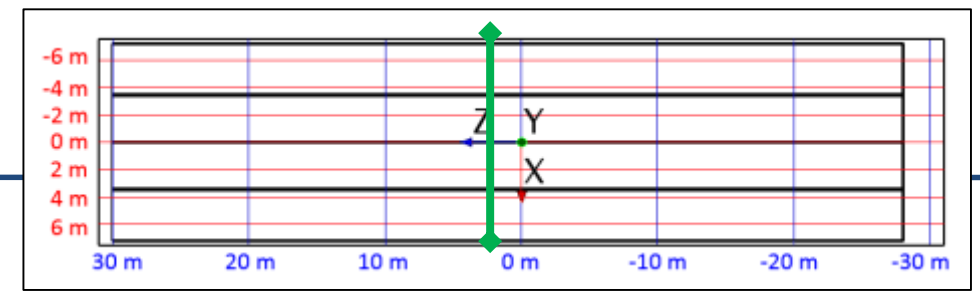


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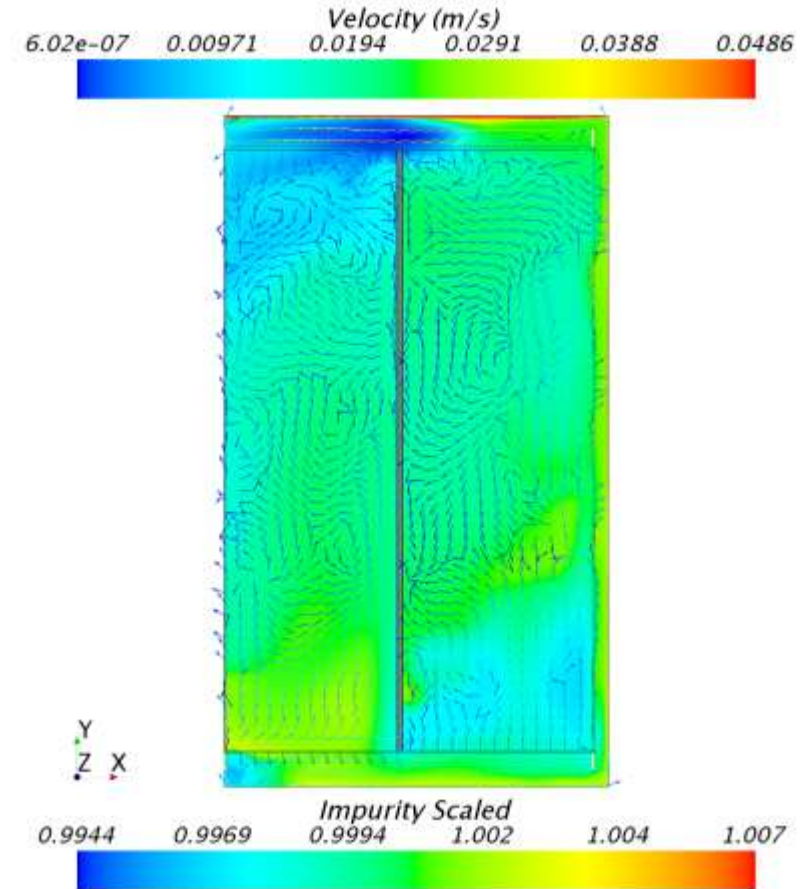


Electronics Off

Electronics Off: Impurity at Z = 2.59 m Between Inlet and Outlet

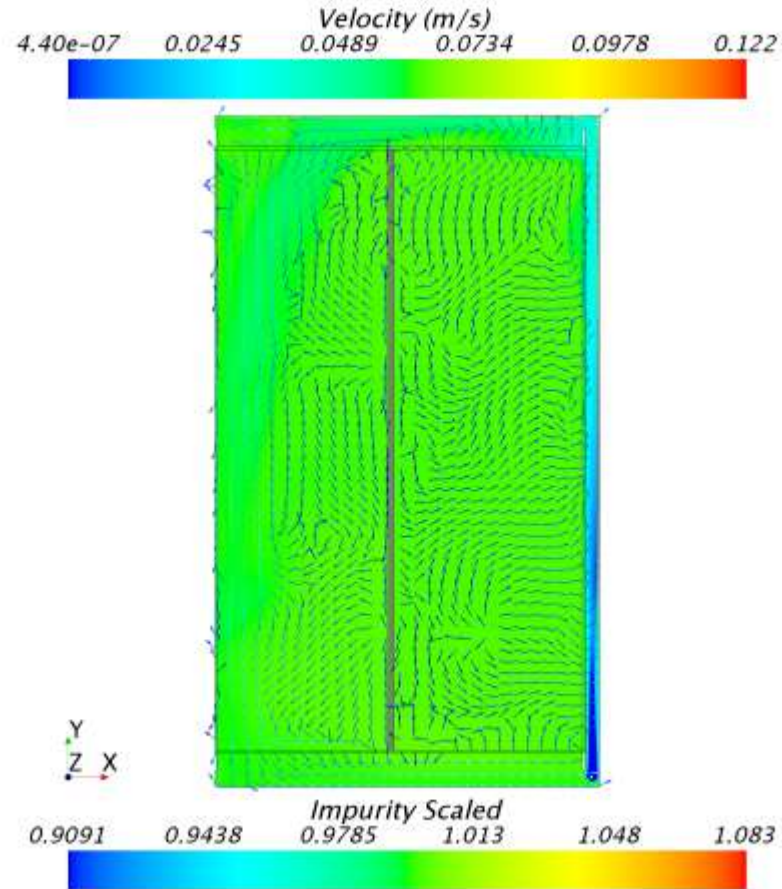
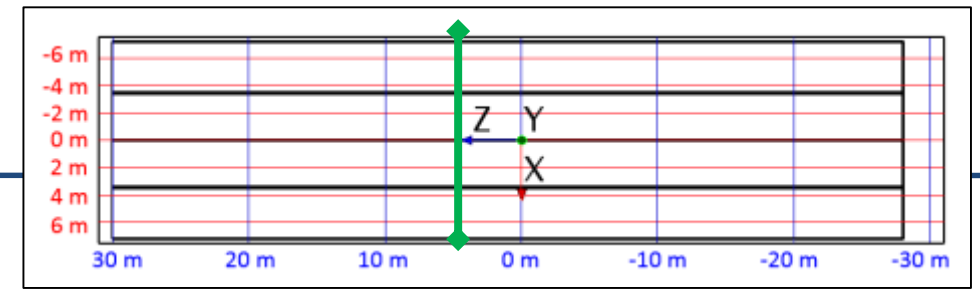


Electronics On

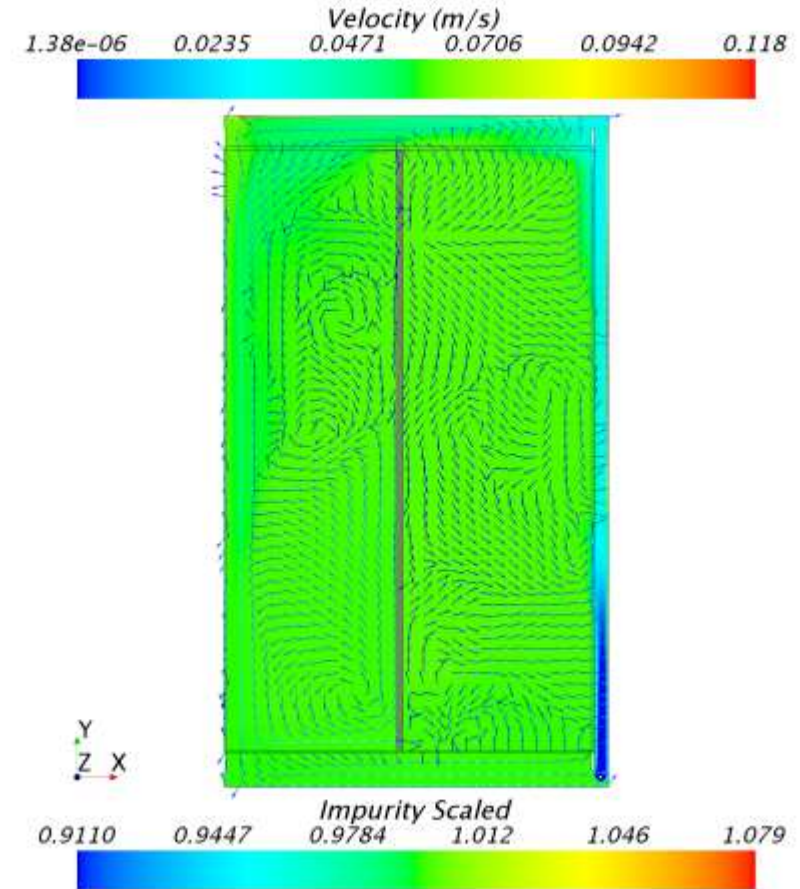


Electronics Off

Electronics Off: Impurity at Z = 5.17 m In Line with Inlet

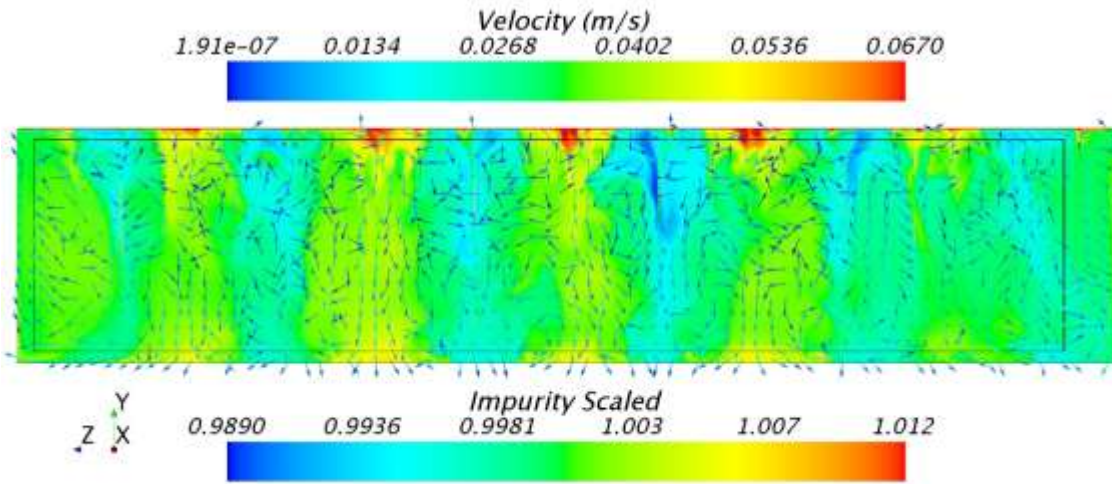
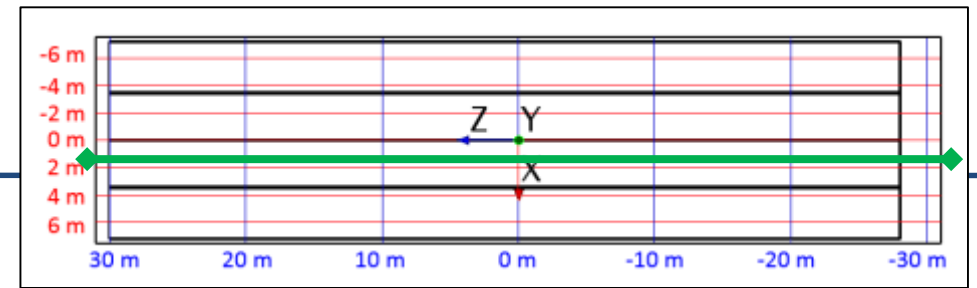


Electronics On

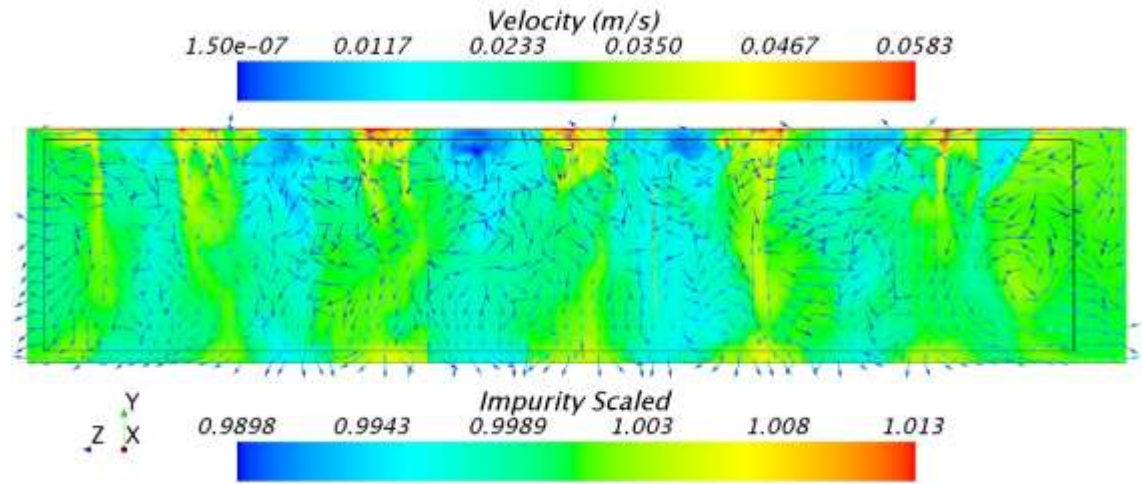


Electronics Off

Electronics Off: Impurity at X = 1 m

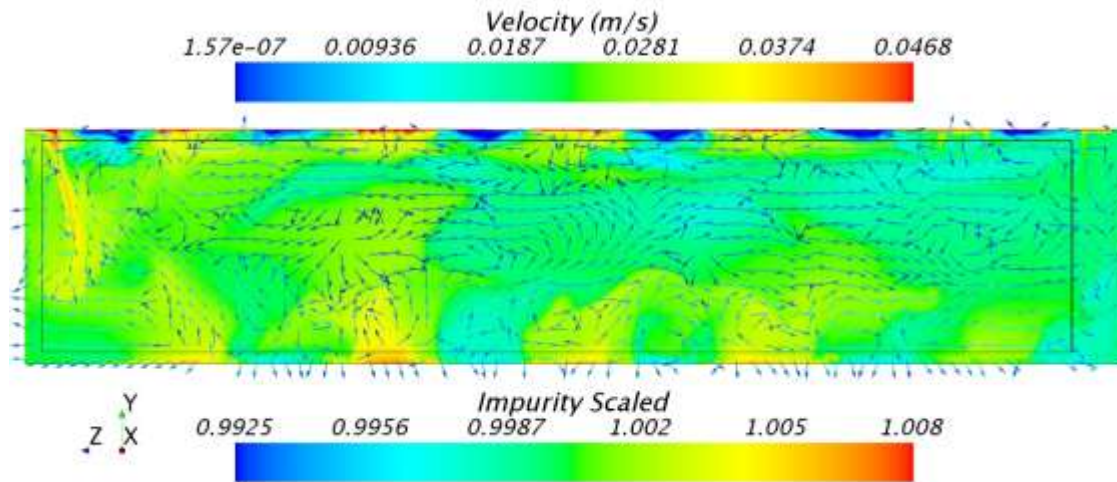
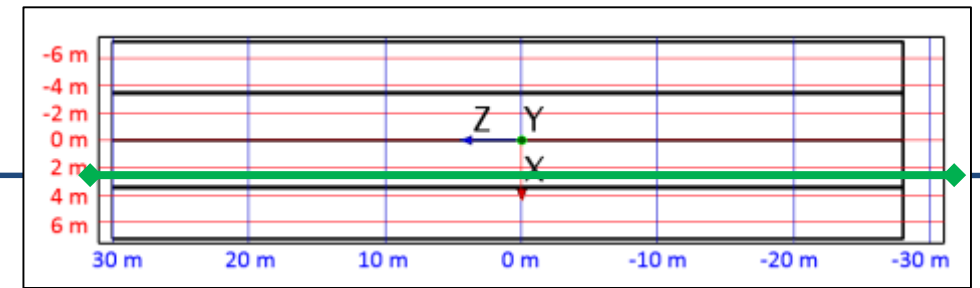


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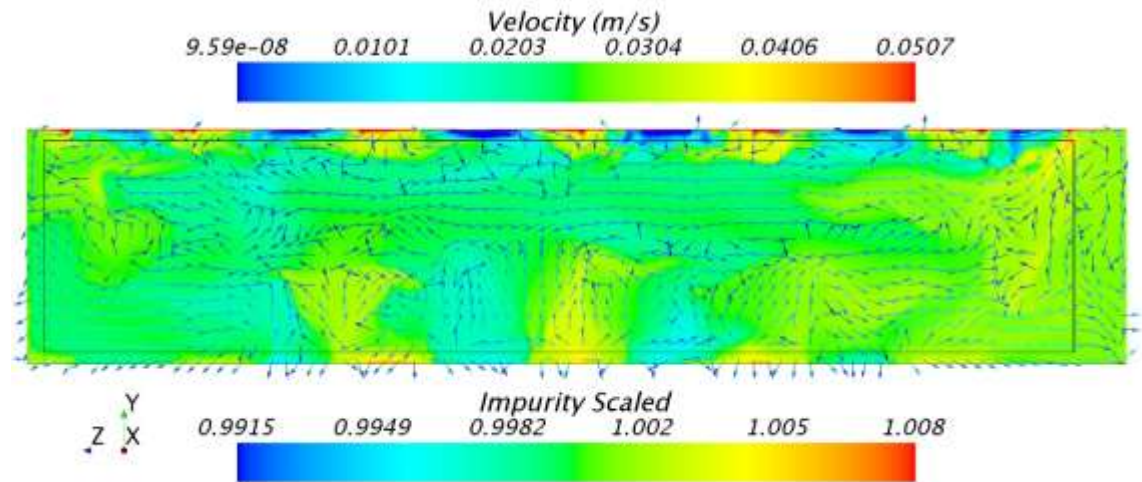


Electronics Off

Electronics Off: Impurity at X = 3 m

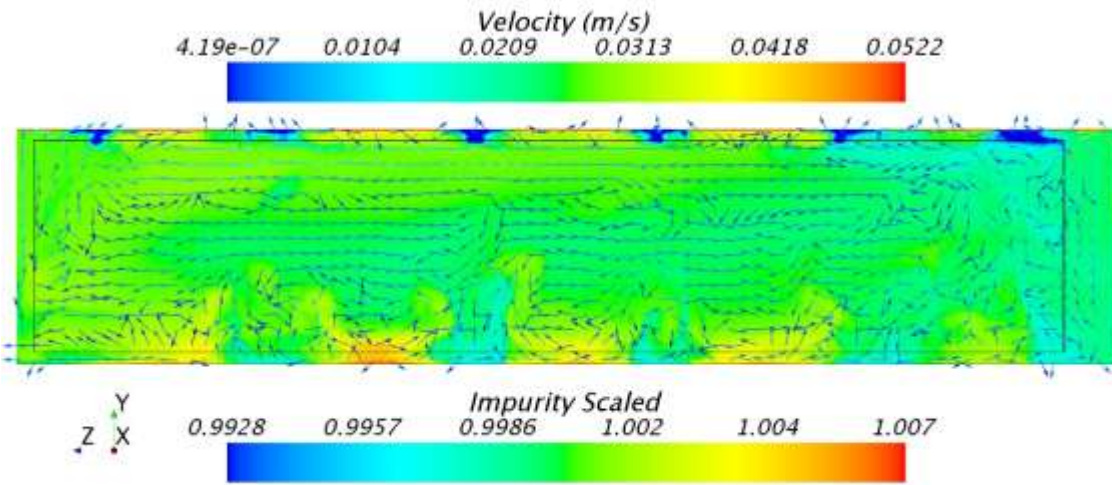
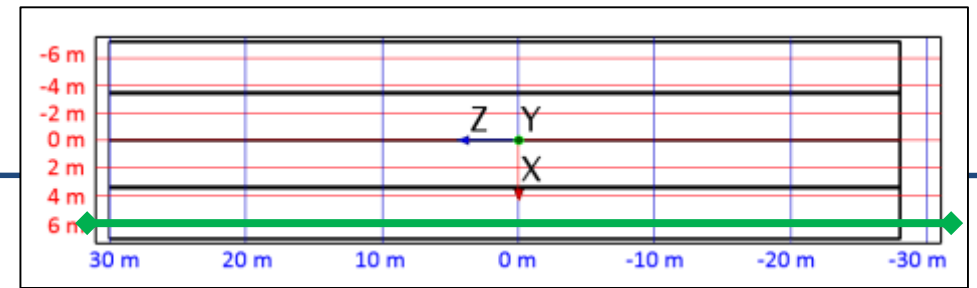


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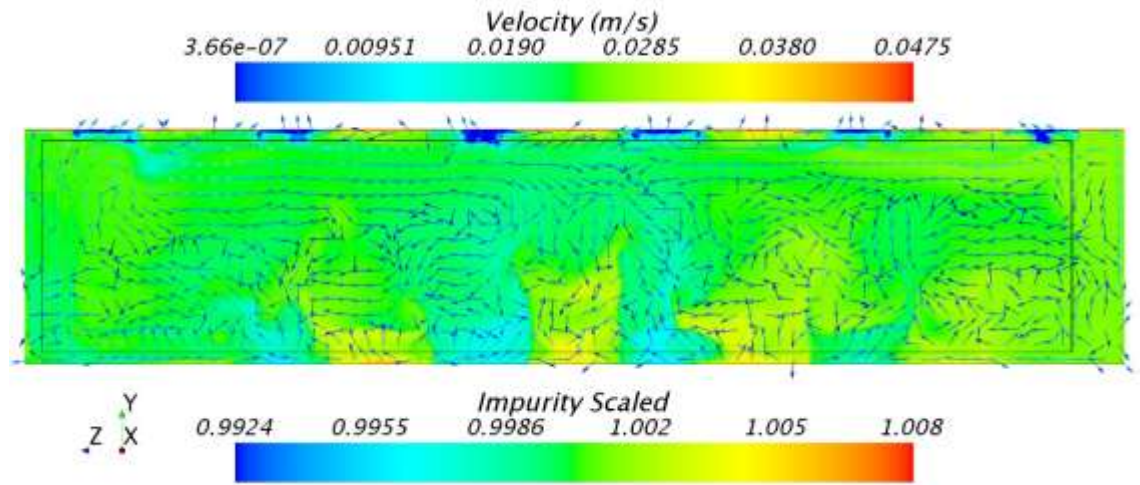


Electronics Off

Electronics Off: Impurity at X = 6 m



Electronics On



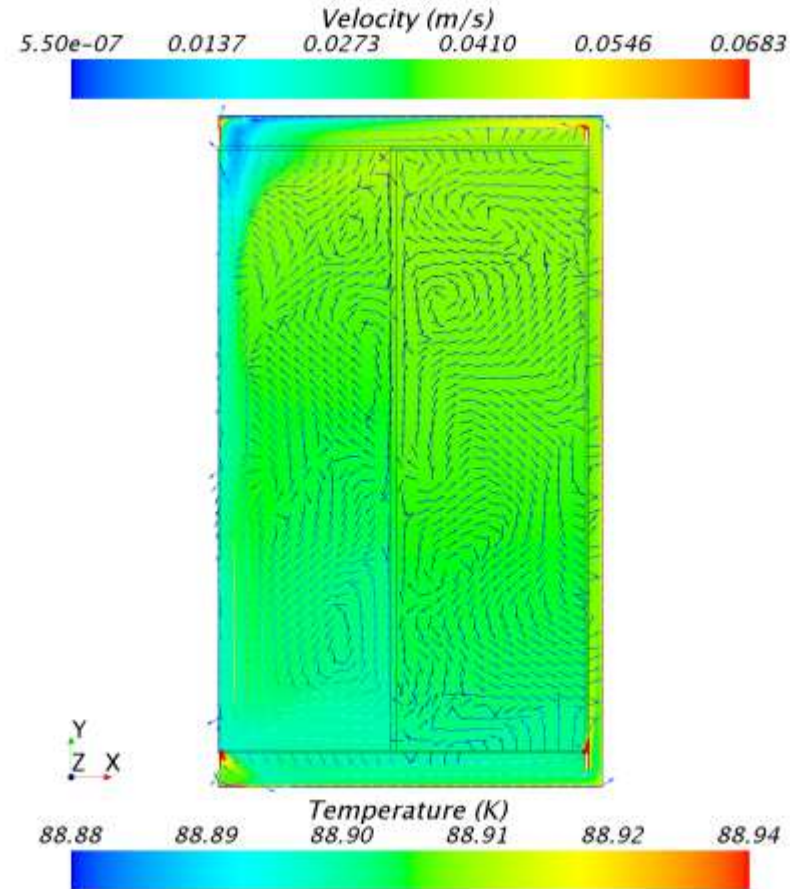
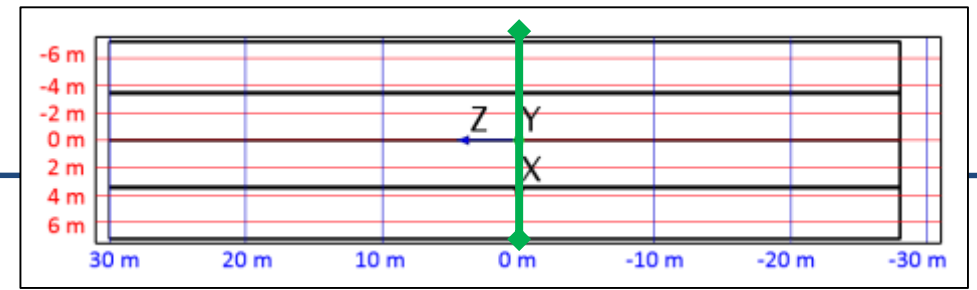
Electronics Off

Half Flow Rate

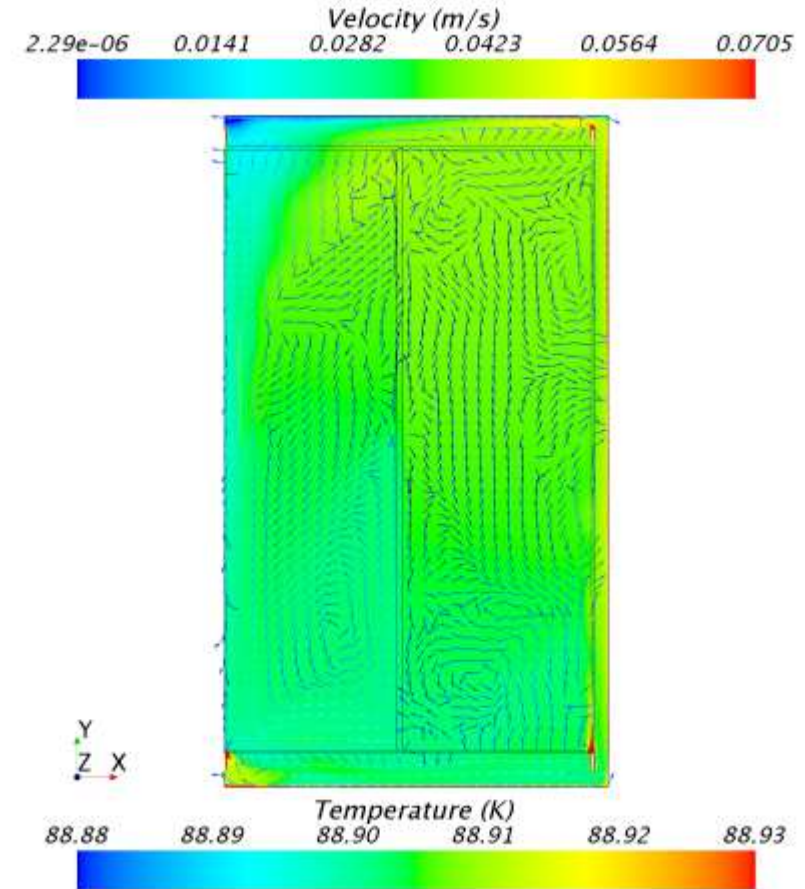
- LAr inlet flow rate changed from 103 GPM to 51.5 GPM



Half Flow Rate: Temperature at $Z = 0.0$ m In Line with Outlet

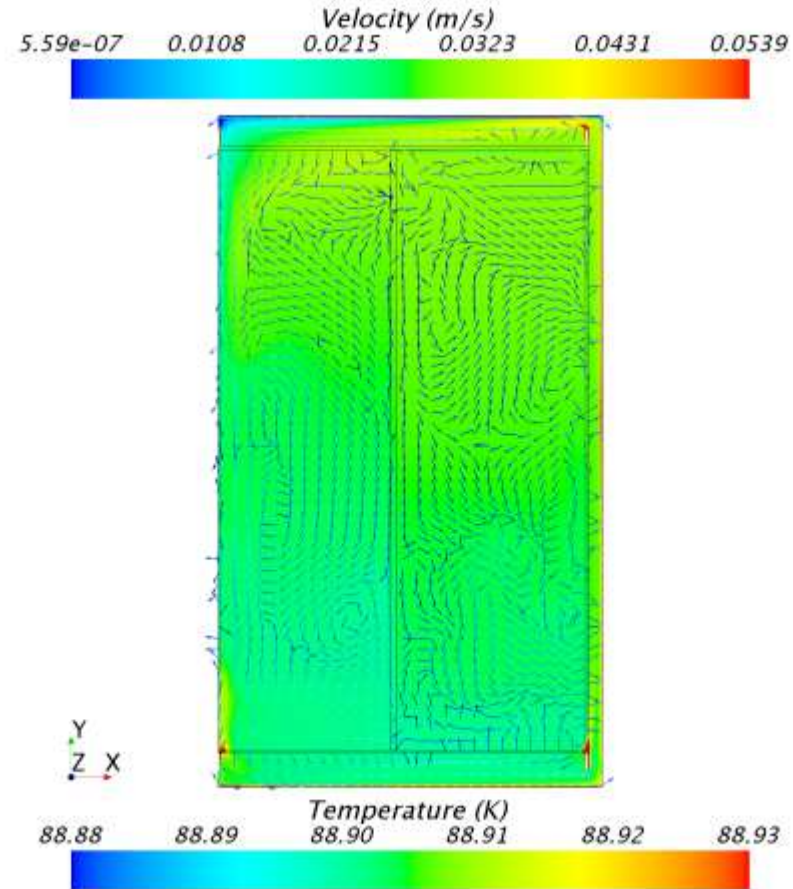
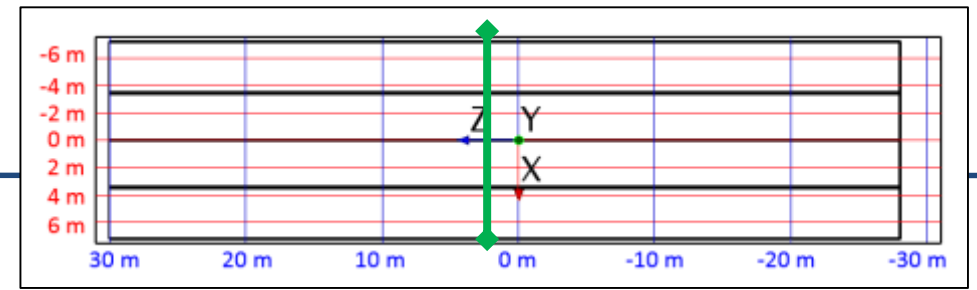


Regular Flow Rate

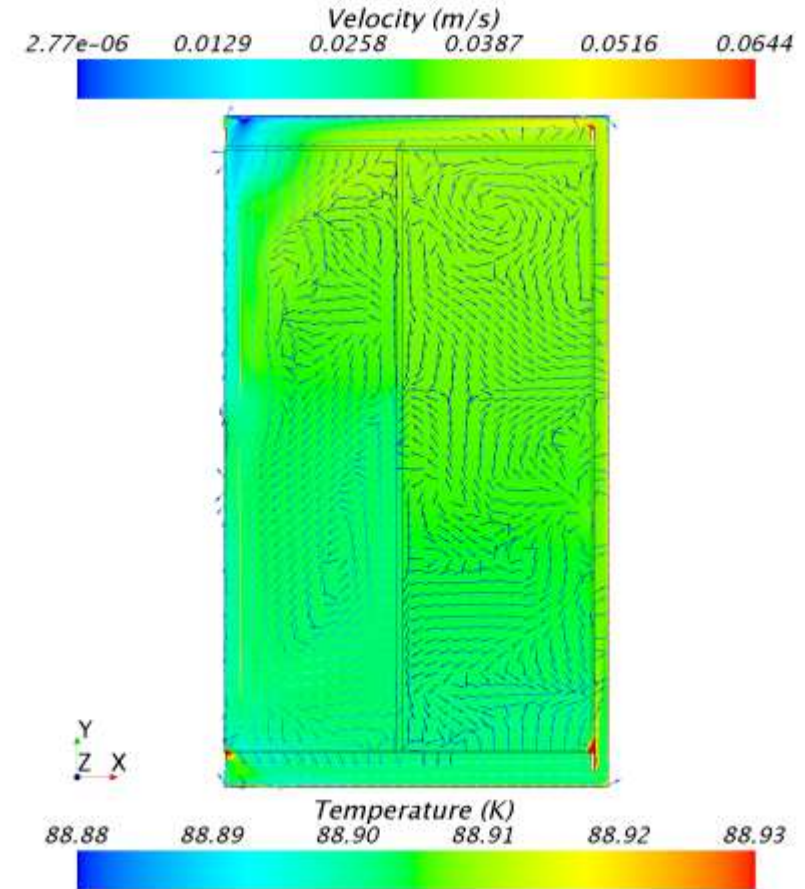


Half Flow Rate

Half Flow Rate: Temperature at Z = 2.59 m Between Inlet and Outlet

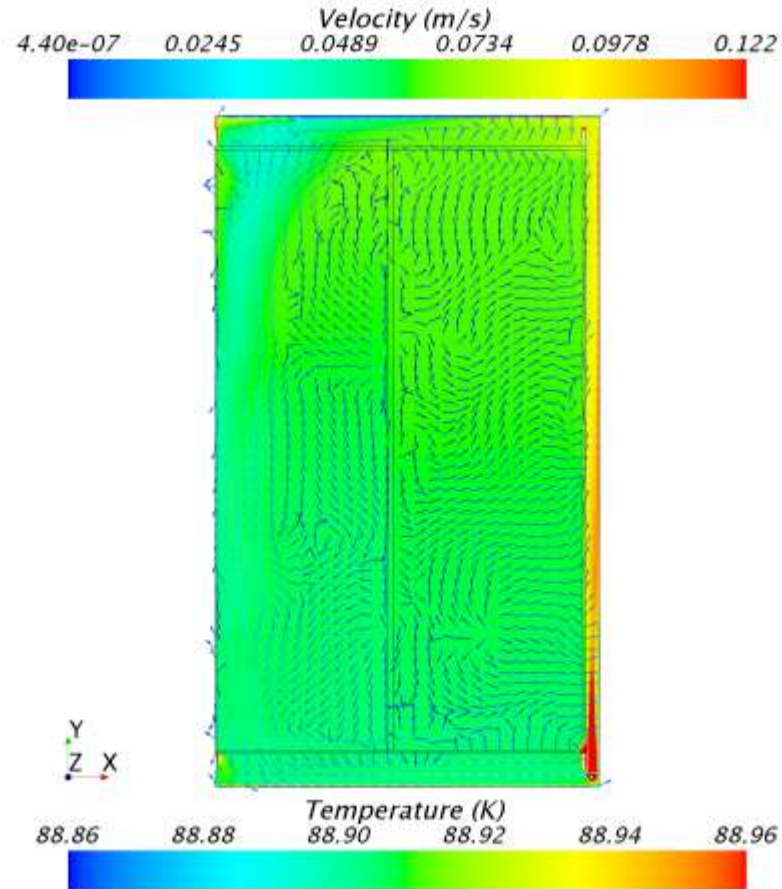
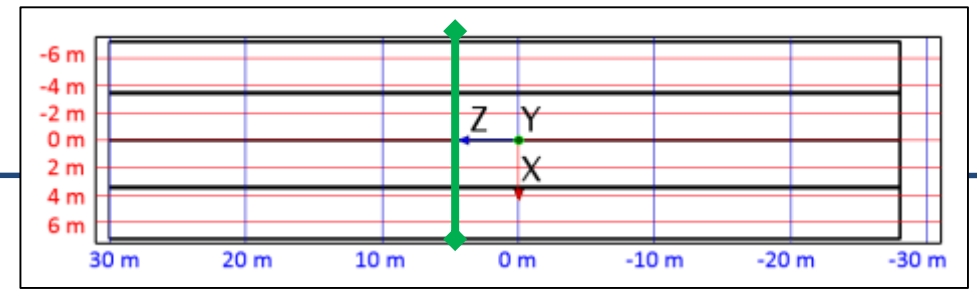


Regular Flow Rate

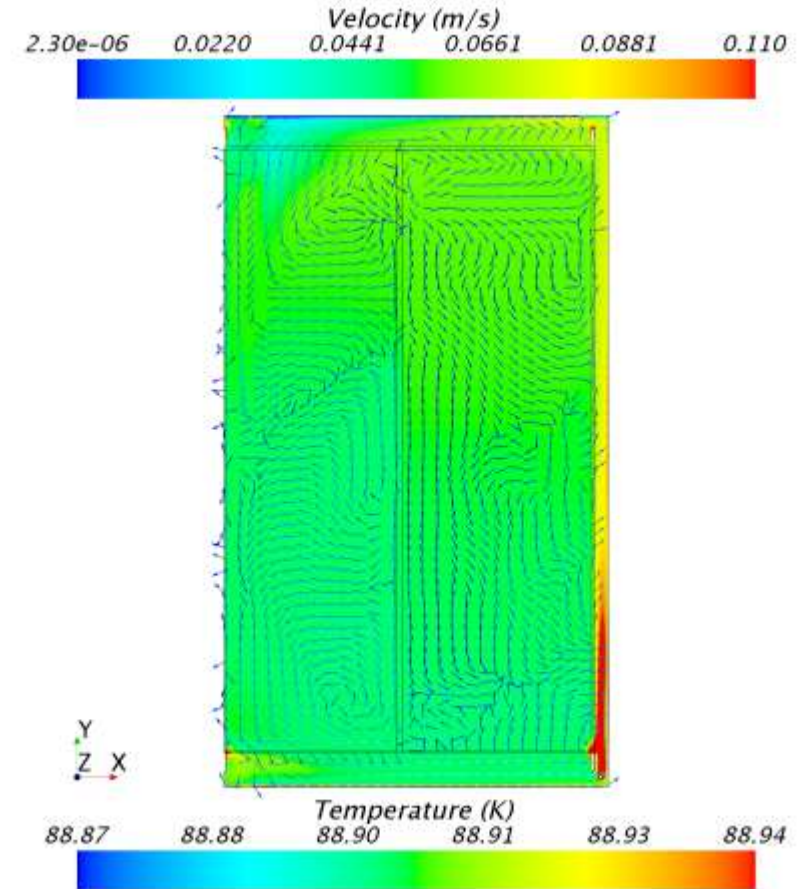


Half Flow Rate

Half Flow Rate: Temperature at Z = 5.17 m In Line with Inlet

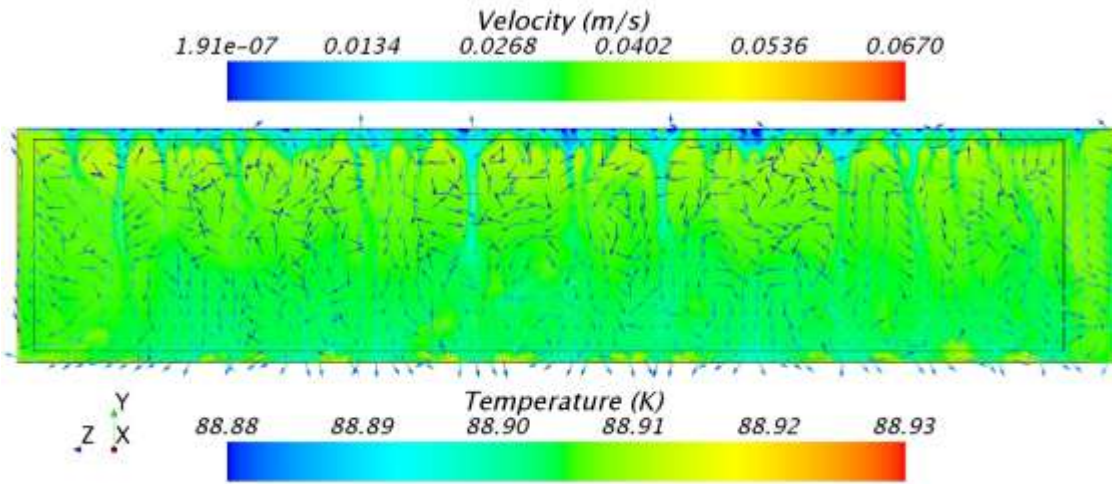
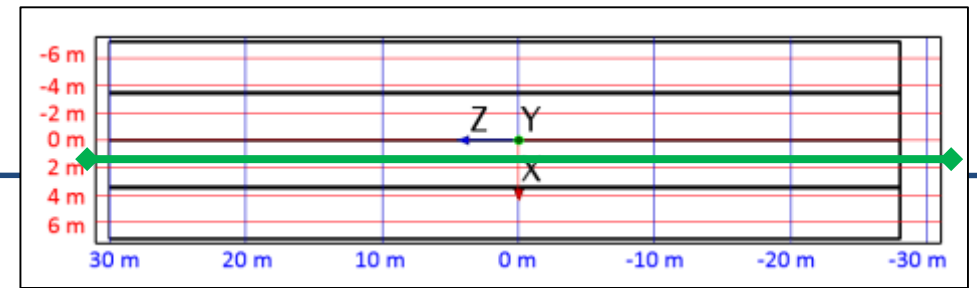


Regular Flow Rate

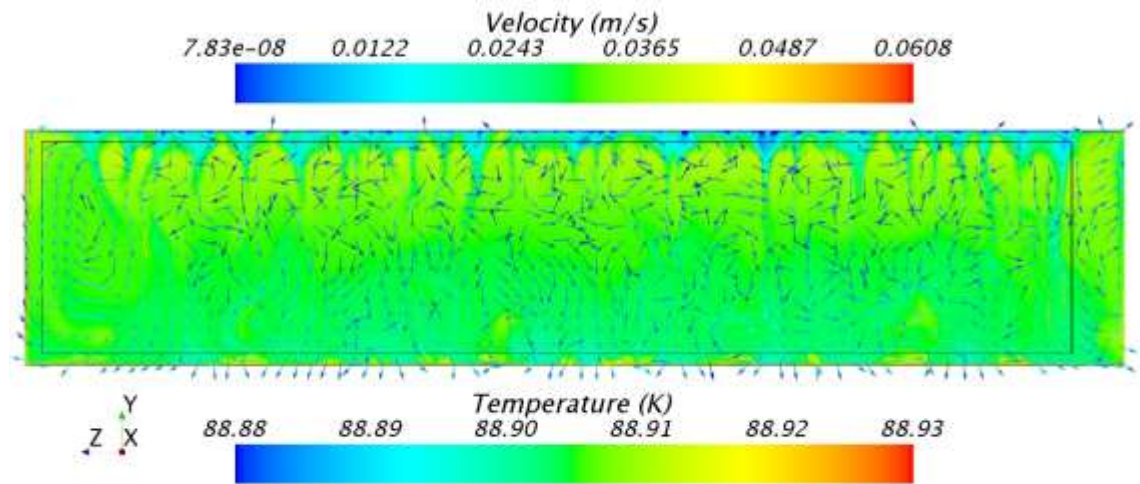


Half Flow Rate

Half Flow Rate: Temperature at X = 1 m

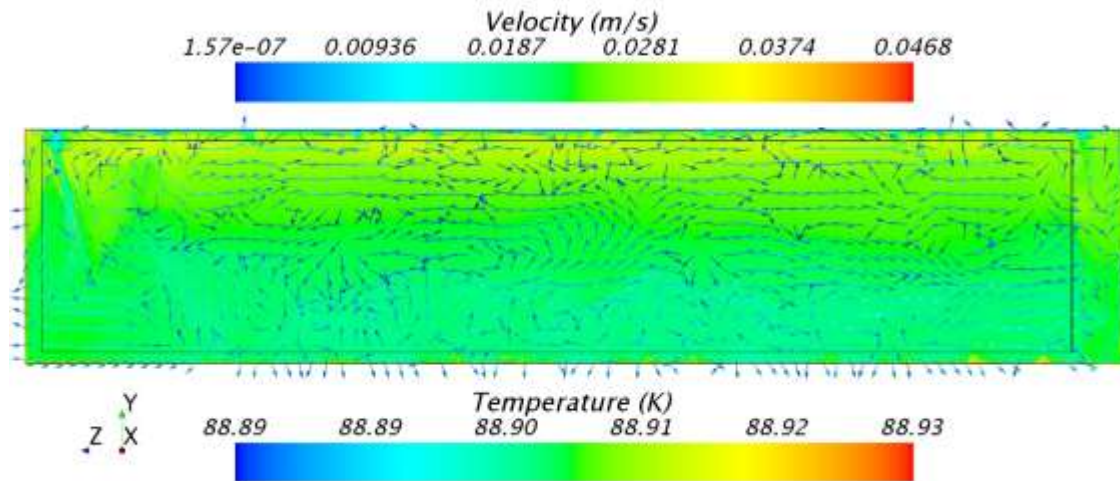
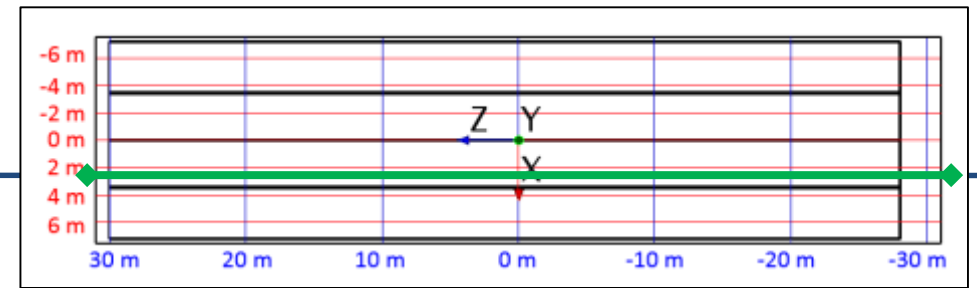


Regular Flow Rate

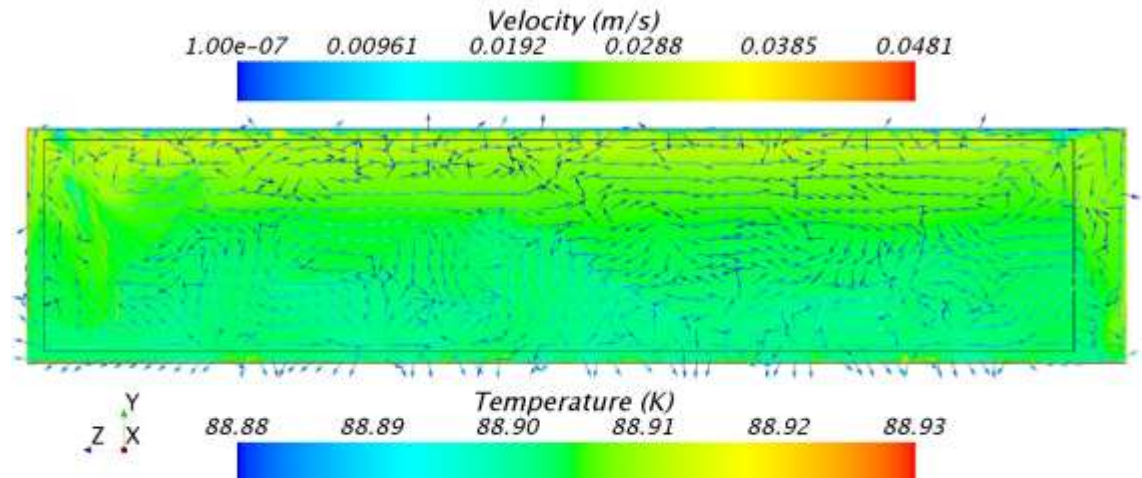


Half Flow Rate

Half Flow Rate: Temperature at X = 3 m

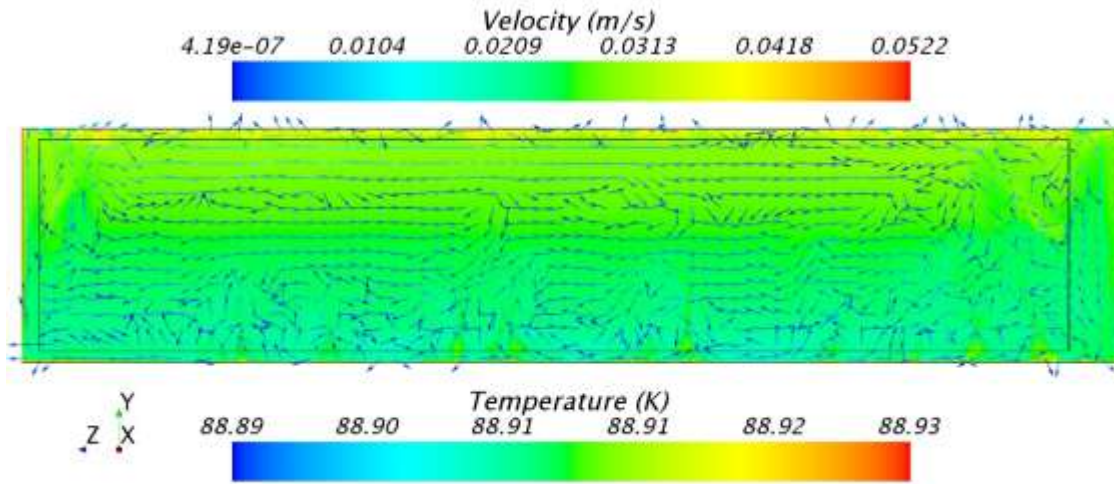
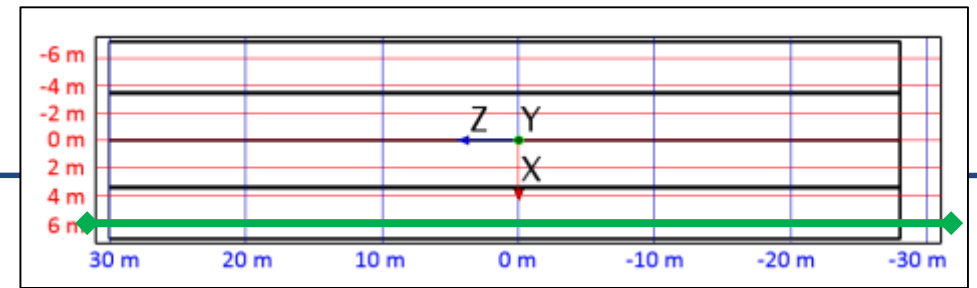


Regular Flow Rate

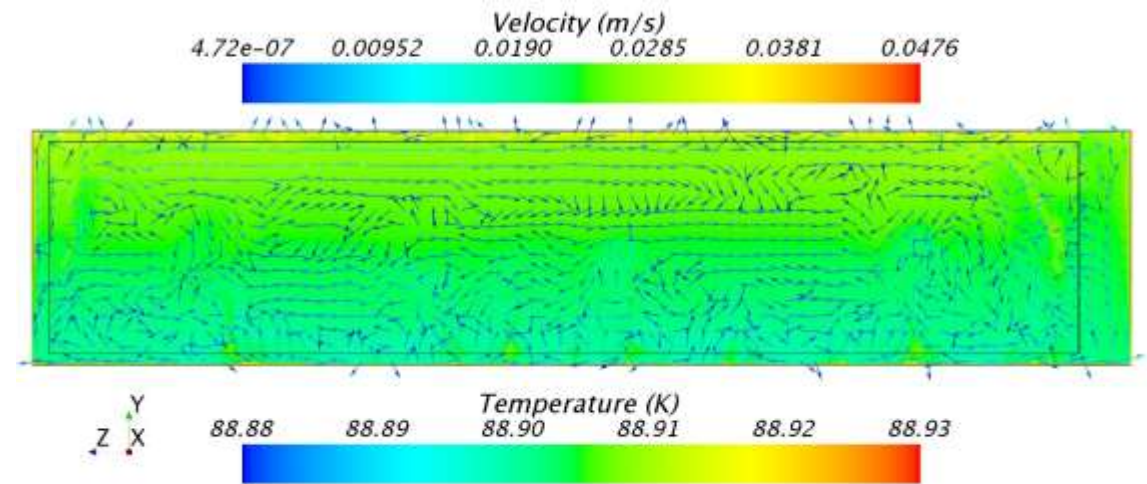


Half Flow Rate

Half Flow Rate: Temperature at X = 6 m

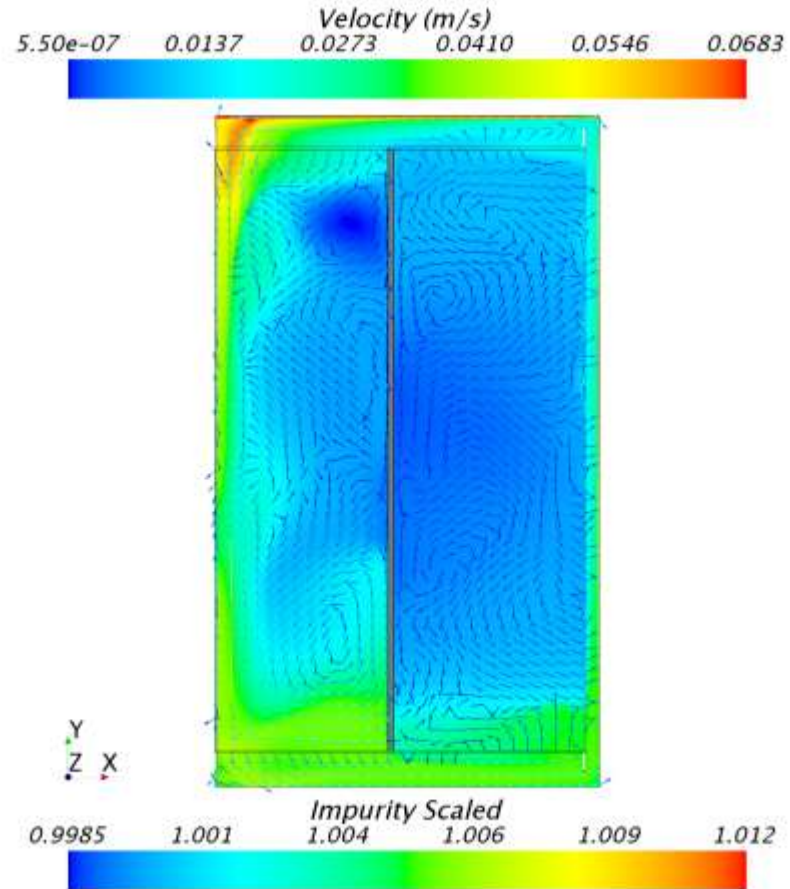
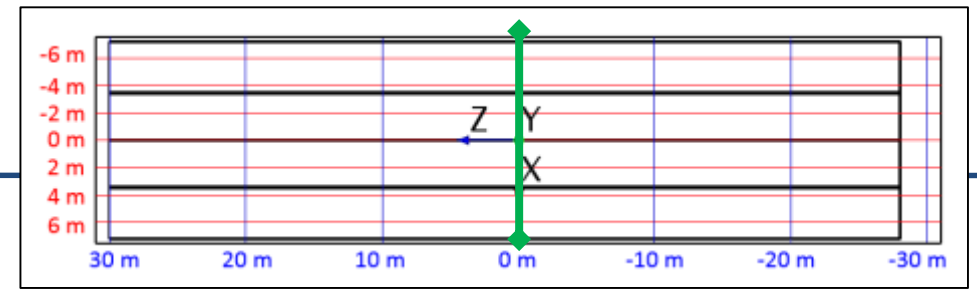


Regular Flow Rate

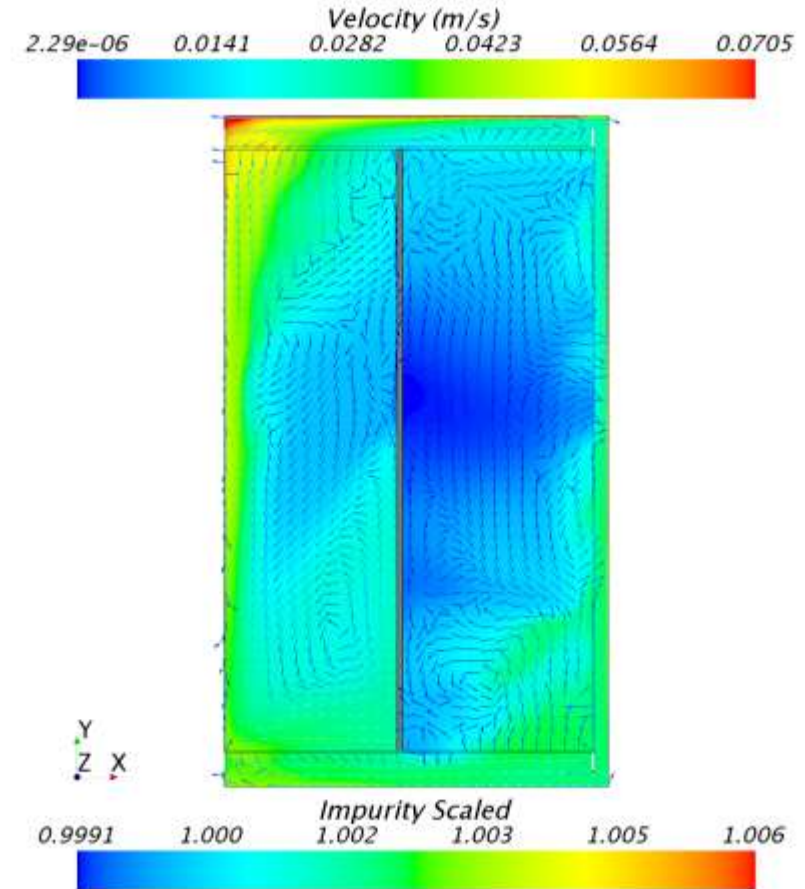


Half Flow Rate

Half Flow Rate: Impurity at Z = 0.0 m In Line with Outlet

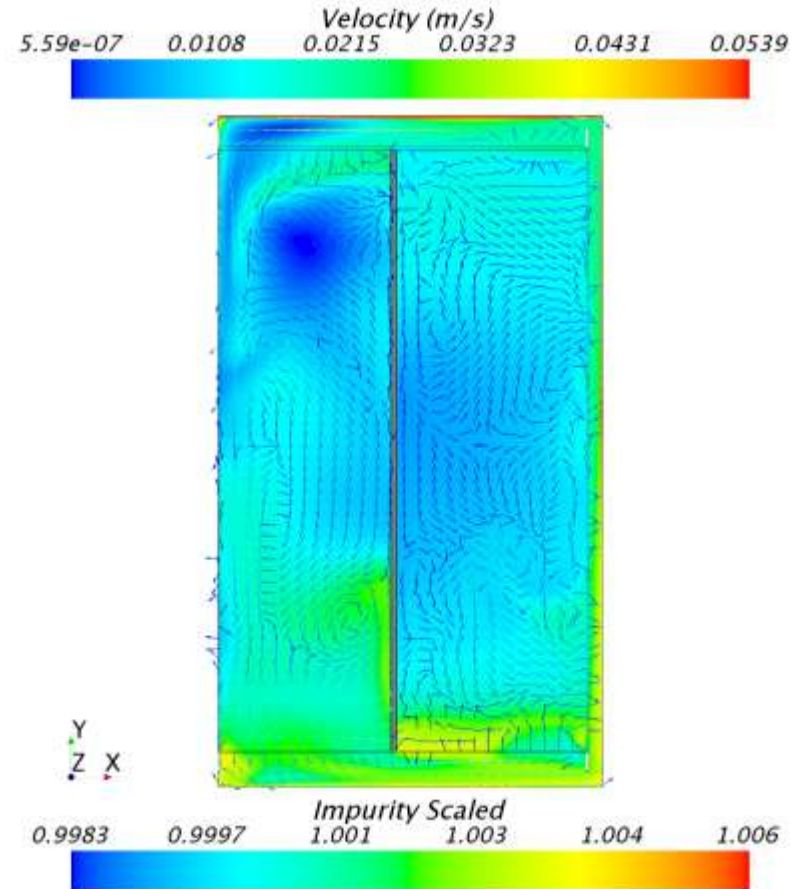
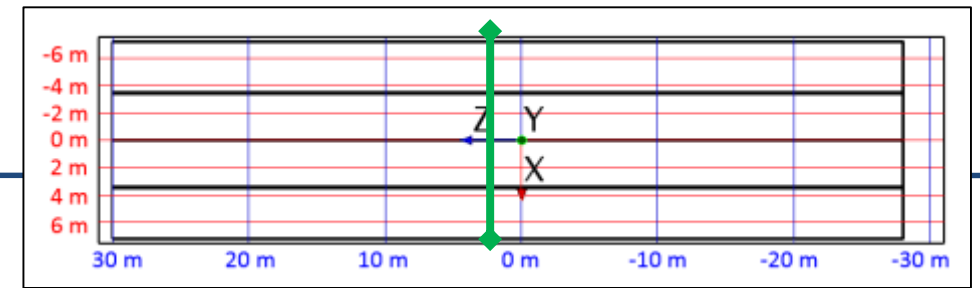


Regular Flow Rate

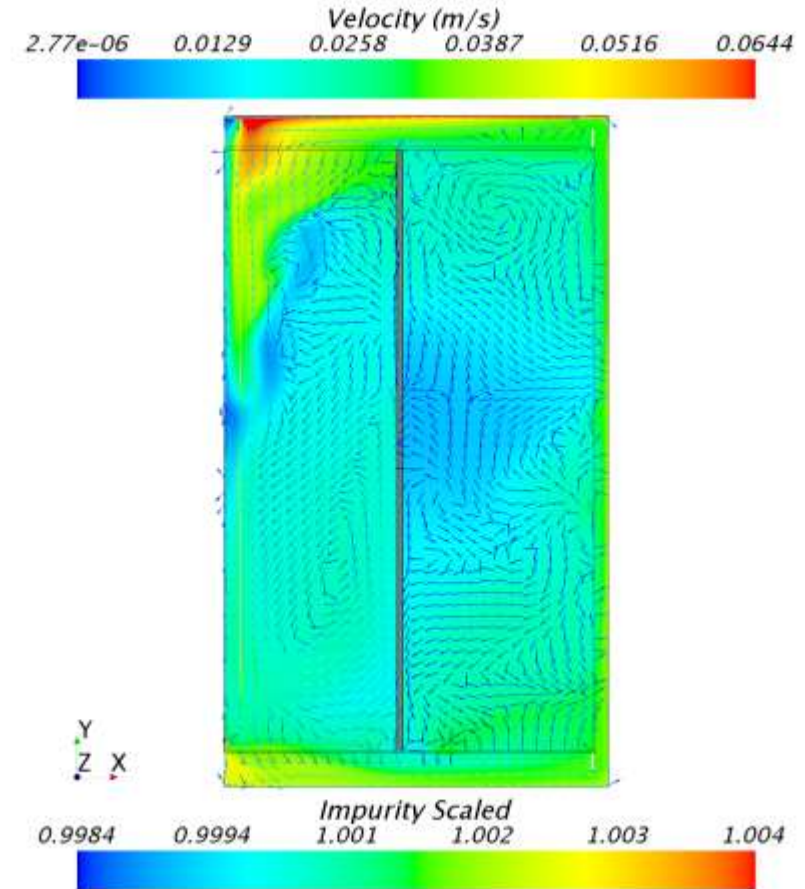


Half Flow Rate

Half Flow Rate: Impurity at Z = 2.59 m Between Inlet and Outlet

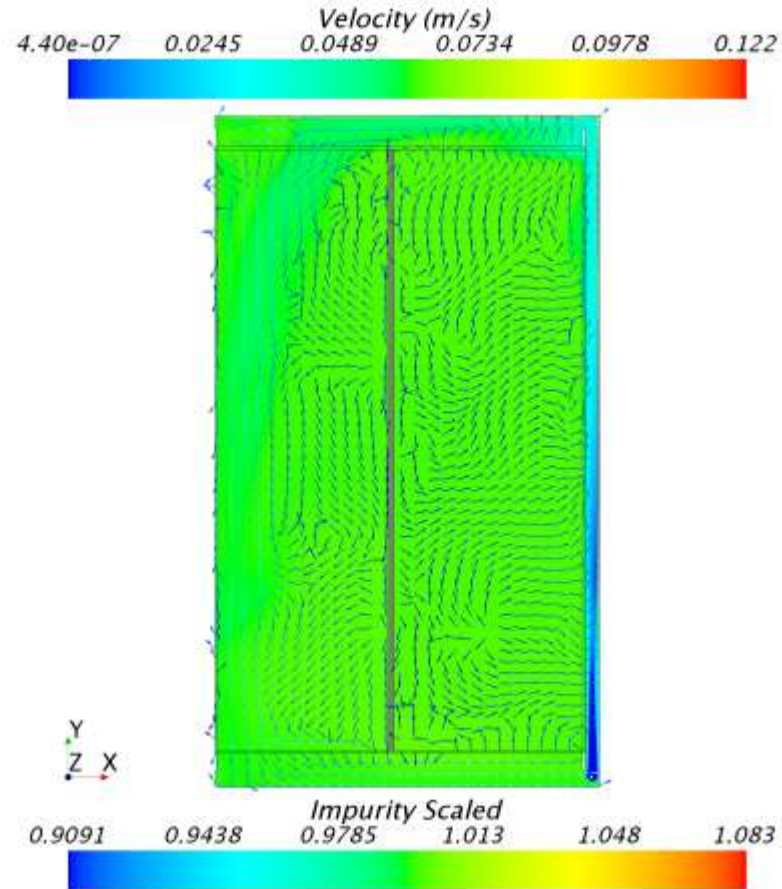
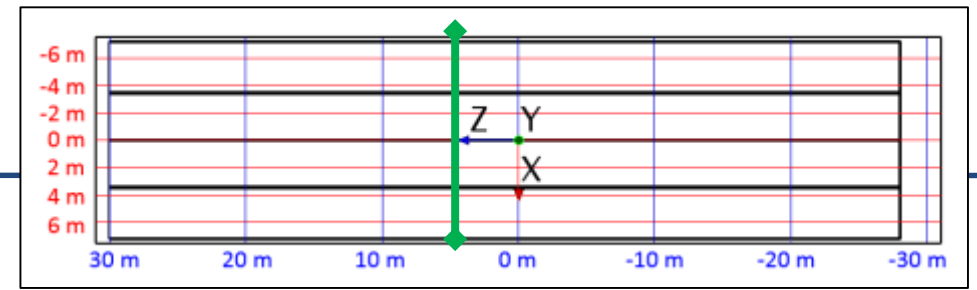


Regular Flow Rate

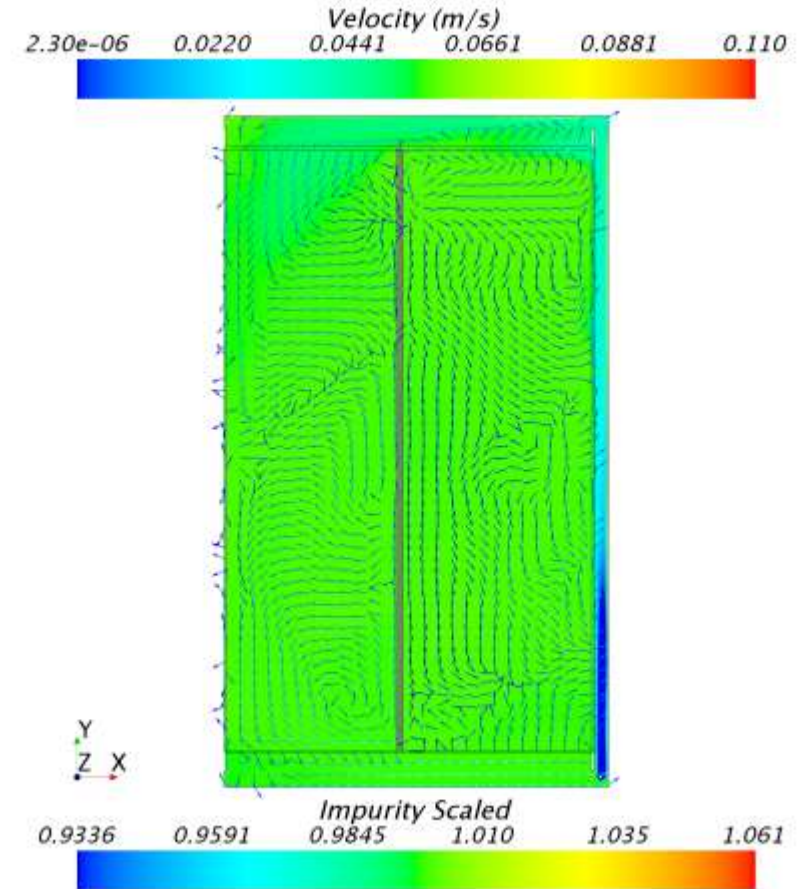


Half Flow Rate

Half Flow Rate: Impurity at Z = 5.17 m In Line with Inlet

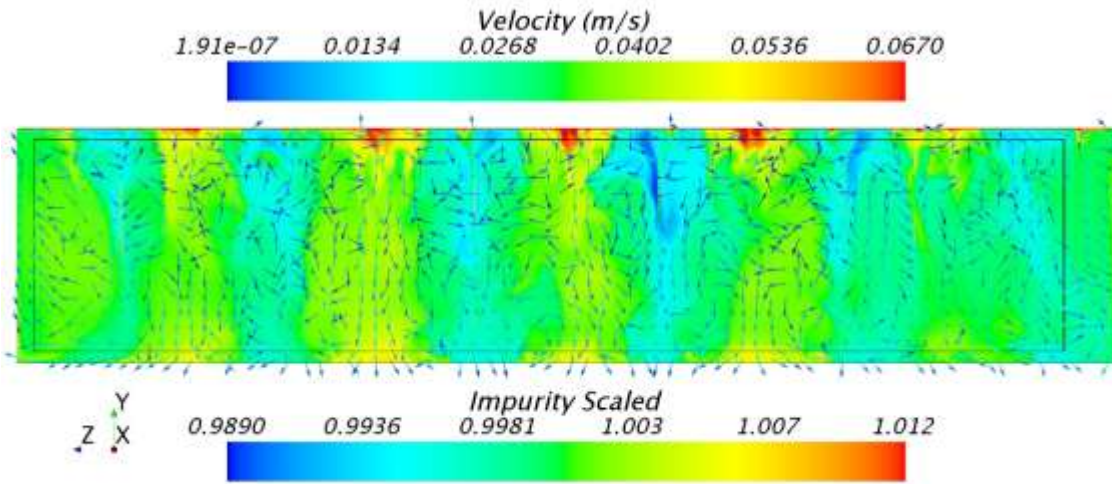
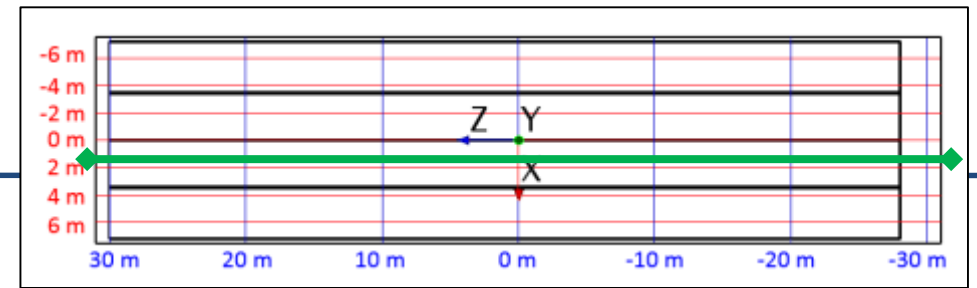


Regular Flow Rate

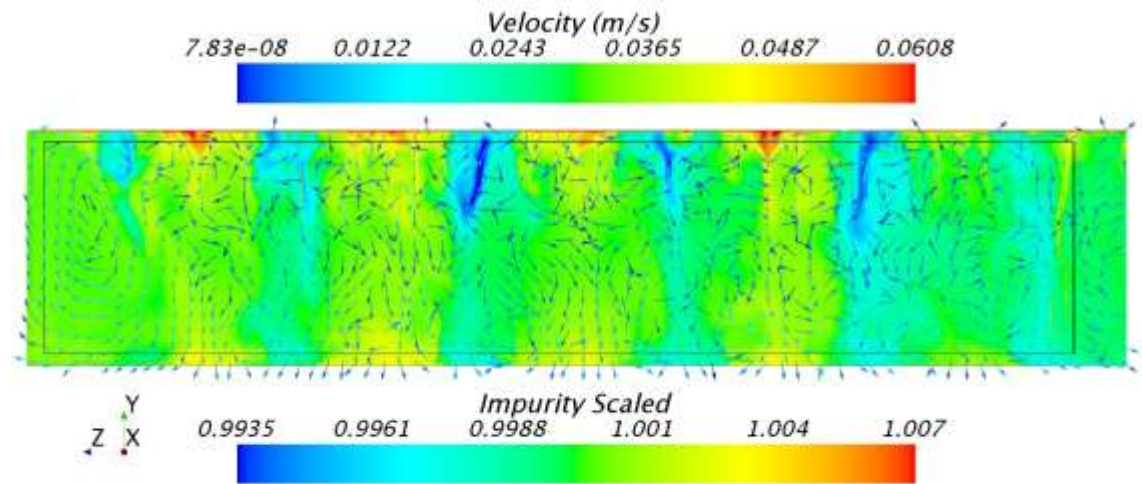


Half Flow Rate

Half Flow Rate: Impurity at X = 1 m

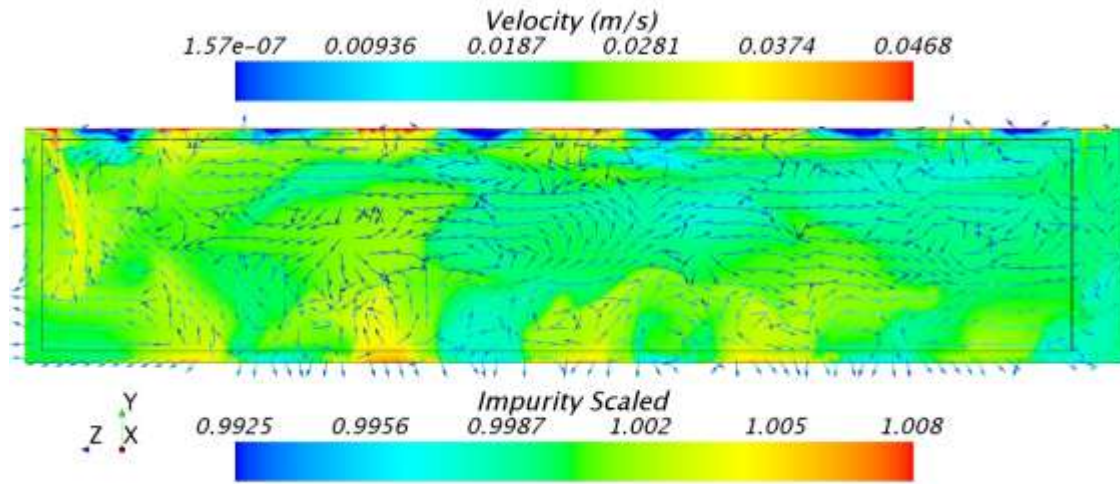
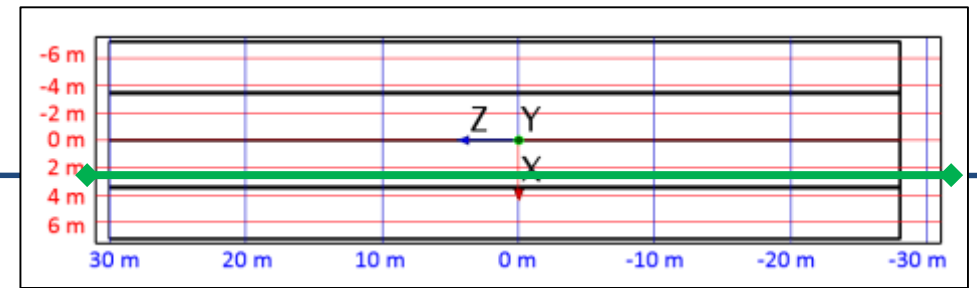


Regular Flow Rate

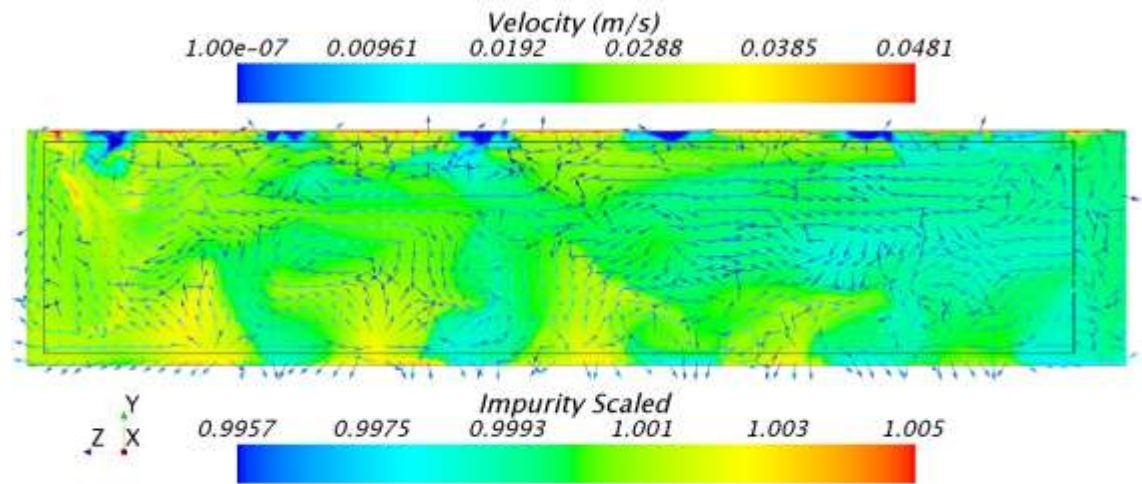


Half Flow Rate

Half Flow Rate: Impurity at X = 3 m

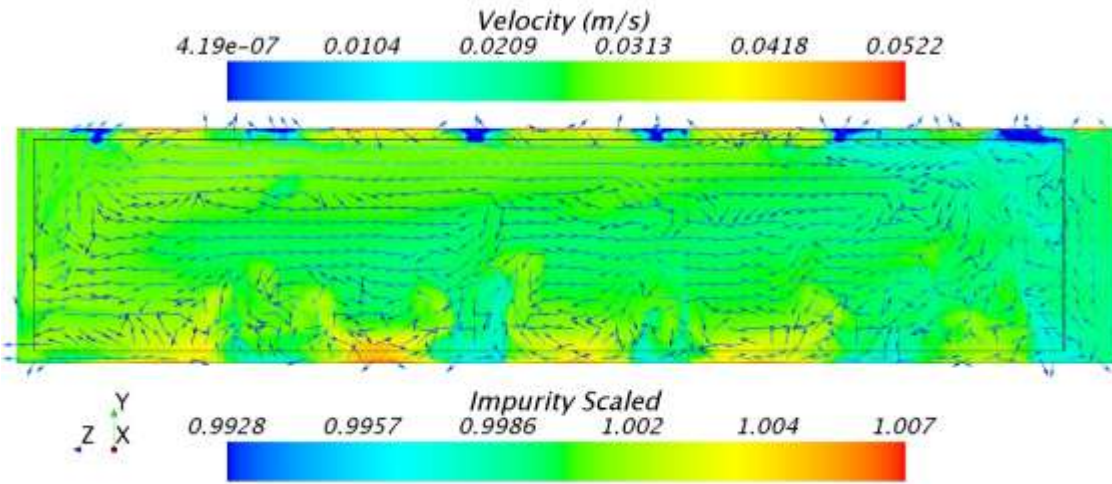
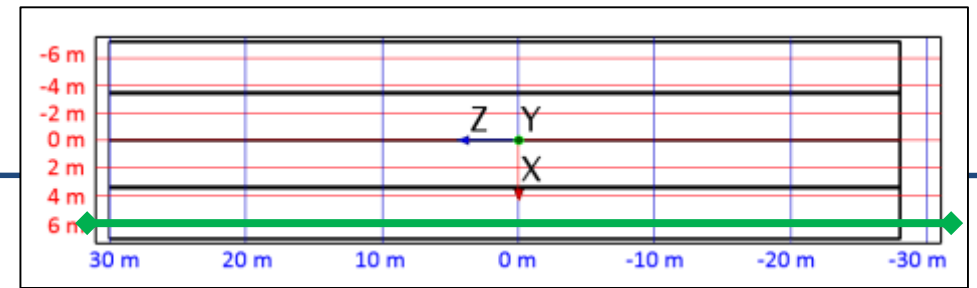


Regular Flow Rate

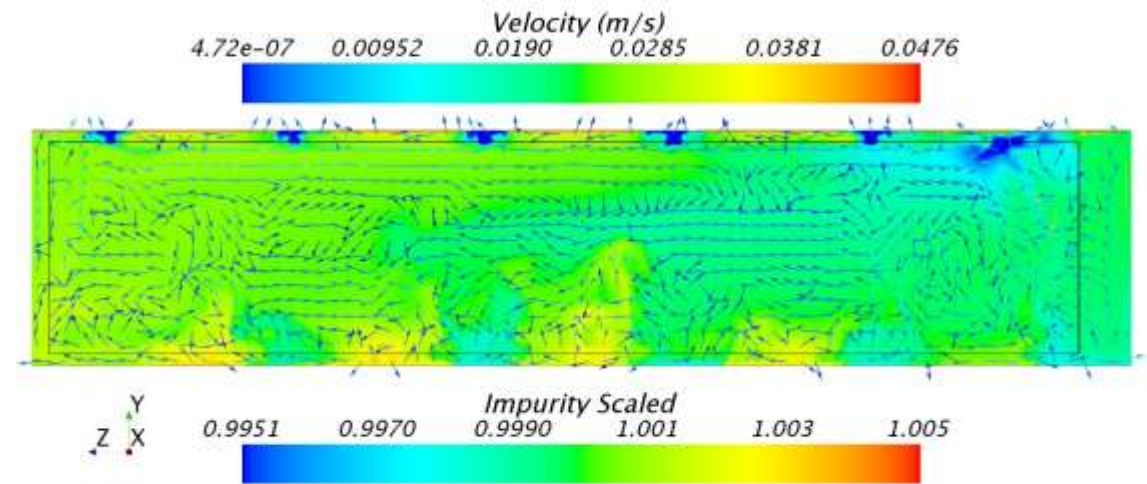


Half Flow Rate

Half Flow Rate: Impurity at X = 6 m



Regular Flow Rate



Half Flow Rate

Latest Design: Field Cage Impurity Range Information

- Turning off the electronics does not significantly affect the scaled min/max or standard deviation.
- Half LAr recirculation rate decreases the max value and standard deviation

Simulation with Trimmed Mesh Variation:

- Scaled max: 1.13% to 1.58%
- Scaled min: -3.44% to -12.91%
- Standard Deviation: 1.59E-03 to 1.88E-03

Field Cage Impurity Values: scaled so that the average impurity in the field cage is equal to 1. Table lists percent above/below average.						
	V1 Design	Poly	New Poly	Trimmed	No Elec	Half Flow
Max Value	7.9%	2.13%	1.27%	1.34%	1.51%	0.71%
Min Value	-11.8%	-4.76%	-4.30%	-5.93%	-4.24%	-3.20%
Standard Dev.	1.63E-02	1.41E-03	1.38E-03	1.72E-03	1.70E-03	1.04E-03

Simulation with Trimmed Mesh and Half Flow Rate Variation:

- Scaled max: 0.60% to 0.87%
- Scaled min: -1.68% to -9.65%
- Standard Deviation: 9.04E-04 to 1.21E-03



Future Work

- Full (not symmetric) model of latest design
 - Erik Voirin's simulation showed significant asymmetry.
- Add monitors to track unsteadiness:
 - Monitor fluctuation in scaled min. and max. field cage impurity.
 - Track location of scaled min. and max. field cage impurity.
 - Monitor field variance in impurity distribution
- Possibility of simulating ProtoDUNE.

